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Analysis of the Radio-ecological State of Units and Installations Involved in Nuclear Submarine Decommissioning in the Northwest Region of Russia

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14. ABSTRACT

This report documents the current state of nuclear submarines and facilities involved in the dismantlement of nuclear submarines in the Russian Northern Fleet. In the first section of the report, all nuclear-powered units and installations involved in the process of nuclear submarine utilization in the northwest region of Russia are listed and considered in detail. The units and installations that were studied include: decommissioned nuclear submarines to be dismantled and salvaged, maintenance support vessels, coastal servicing enterprises, and coastal sites. The second section of the report deals with the state of the environment within territories and water areas located close to nuclear-powered units and installations involved in nuclear submarine utilization processes in the northwest region of Russia. The third section considers the issues of creating the concept of environmental (ecological) monitoring within the northwest region. In the fourth section of the report, an analysis of standard and legal frameworks for nuclear submarine utilization is given.

15. SUBJECT TERMS

Nuclear submarine; Russian Northern Fleet; Submarine dismantlement; Radioactive waste; Arctic environment

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ABBREVIATIONS AND CONVENTIONS

AC	Admissible Concentrations	ДК
AF	Activity Filter	ФА
AFC	Activity Filter Cooler	ХФА
AIRC	Automated Information-Reference System	
ASCRS	Automated System of Control over Radiation Situation	
Assembl. 42	Automatic Rod Control System–ARCS	Сб.42
Assembl. 43	Scram Rod Control System –SRCS	Сб.43
Assembl. 60	Technical Code of CPPC	Сб.60
ATRP-R	Advanced Technology Research Foundation	МНТП РАО
BA	Buffer Area	СЗЗ
BP	Biological Protection	БЗ
BPT	Biological Protection Tank	ЦБЗ
CC	Concrete Container	БК
CDS	Control Dosimetric Station	КДП
CG (CPS CR)	Compensate Group of CPS Control Roads	КР
Chernobyl NPP	Chernobyl Nuclear Power Plant	ЧАЭС
CPPC	Centrifugal Pump of the Primary Circuit	ЦН ПК
CPS	Control and Protection System	СУЗ
CSE	Coastal Servicing Enterprise	БТБ
DBMS	Data Base Management System	
DD	Dry Dock	СД
DPNS	Diesel-Power Nuclear Submarine	ДПЛ
DR	(Exposure) Dose Rate	МЭД, МД
DSAP	Department of Safety Arrangement and Precautions	ООТ
DSB	Dry Storage Block	БСХ
FA	Fuel Assembly	ТВС

FCDM	Floating Control-Dosimetric Mooring	ПКДП
FCh (F)	Fuel Channel With Non-Irradiated Fuel	СТК
FE	Fuel Element	ТВЭЛ
FEI	Physics-Energetic Institute	ФЭИ
FIAC	Federal Information and Analytical Center (Roshydromet)	
FRZ	Free Regime Zone	ЗСвР
FSE	Floating Servicing Enterprise	ПТБ
FSFA	Faulty Spent Fuel Assembly	ДОТВС
FSh	Floating Shop	ПМ
FSUE	Federal State Unitary Enterprise	ФГУП
GCC	Gorno-Chemical Combinate	ГХК
GIS	Geographic Information System	
GRW	Gaseous Radioactive Wastes	ГРО
HPG	High-Pressure Gas	ГВД
IAC	Information and Analytical Center	
IBRAE RAN	Nuclear Safety Institute	
IER	Ion-Exchange Resin	ИОС
IRS	Ionizing Radiation Source	ИИИ
IWP	Iron-Water Protection	ЖВЗ
LCC	Local Crisis Centers	
LMC	Liquid-Metal Coolant	ЖМТ
LRW	Liquid Radioactive Wastes	ЖРО
MAC	Maximum Allowable Concentration	ПДК
MCC	Metal-Concrete Container	МБК
MSNE PC	“Murmansk Sea Navigation Enterprise” Public Corporation	ММП
NDHS	North Department of Hydrometeorological Service	
NF	Nuclear Fuel	ЯТ
NIIAR	Institute of Nuclear Reactors (Dimitrovgrad)	НИИАР
NMSV	Nuclear Maintenance Support Vessel	САТО

No English Abbreviation	Pressurizer	КО
No English Abbreviation	Type of Reactor	ВМ-А
No English Abbreviation	Type of Reactor	ВМ-4
No English Abbreviation	Type of Reactor Unit	ОК-300
No English Abbreviation	Type of Reactor Unit	ОК-350
No English Abbreviation	Type of Reactor Unit	ОК-700
No English Abbreviation	Type of Reactor Unit	ОК-650
No English Abbreviation	Navy	ВМФ
No English Abbreviation	Environment	ОПС
No English Abbreviation	Radiation Safety	РБ
NPP	Nuclear Power Plant	АЭС
NRB	Natural Radiation Background	ПРФ
NRE	Natural Radioelement	ЕРЭ
NRN	Natural Radionuclide	ЕРН
NS	Nuclear Submarine	АПЛ
PA	Production Association	ПО
PDOMB	Pilot Design Office of Machine Building	ОКБМ
PRF	Power Reactor Facility	ЯЭУ
PS	Performance Specification	ТЗ
PWR	Power Water Reactor	
RC	Reactor Compartment	РО
RCA	Radiation Control Area	ЗН
RCC	Regional Crisis Center	
RCS	Radiation Control Station	ПРК
RF Armed	Armed Forces of the Russian	ВС РФ

Forces	Federation	
RMS	Radiation Monitoring Service	
RS	Radioactive Substance	РВ
RSS	Radiation Safety Service	СРБ
RSS-99	Radiation Safety Standards, 1999	НРБ-99
RU	Reactor Unit	
RW	Radioactive Wastes	РАО
S(N)F	Spent (Nuclear) Fuel	ОЯТ
SAS	Surface Active Substances	ПАВ
SCC	Situation Crisis Center (Minatom)	
SCC	Siberian Chemical Combinate	СХК
SCF	Steam Generating Facility	
SE	Safety Engineering	ТБ
SEP	Spent Extractable Parts of LMC Reactor	ОВЧ
SEM	System of Ecological Monitoring	
SFA	Spent Fuel Assembly	ОТВС
SFUE	Spent Fuel Unitary Enterprise	
SG	Steam Generator	ПГ
SGF	Steam Generator Facility	
SMBE	State Machine Building Enterprise	ГМП
SPI	Steam Producing Installation	ППУ
SRCASh	State Russian Center of Atomic Shipbuilding	
SRE	Service and Repair Enterprise	РТП
SREM	System of Radioecological Monitoring	
SRW	Solid Radioactive Wastes	ТРО
SRW Repository	Solid Radioactive Waste Repository	ХТО
SRY	Ship Repair Yard	
SRZ	Strict Regime Zone	ЗСР
SSh	Surface Ship	НК
SUE ETC	State Unitary Enterprise Emergency Technical Center	

TC	Transportation Cask	ТК, ТУК
TE	Technogenic Effects	ТС
TLD	ThermoLuminescent Dosimeter	ТЛД
TPS	Tactics Performance Specification	ТТЗ
TPT	Technical Pouring Tankers	ТНТ
TSC	Temporary Storage Container	КВХ
TSS	Temporary Storage Station	ПВХ
TT	Technological Tanker	ТТ
TUE	Transuranium Element	ТУЭ
U.N.O.	United Nations Organization	ООН
USACRS	Unified State Automated System of the Control over the Radiation Situation	
USD	U.S. Dollars	
USSR	Union of Soviet Socialist Republics	СССР
USSEM	Unified State System of Ecological Monitoring	
WBI	Waste Burning Installation	УСО
WSA	Waterborne Storage Area (same as WSS, below)	
WSS	Waterborne Storage Site	ПО

ABSTRACT

The Arctic Military Environmental Cooperation Program (AMEC) was established in 1996 with the purpose of providing Norway, Russia, and the United states the opportunity to work together in addressing military-related critical environmental concerns in the Arctic. A key focus area of this program is the spent nuclear fuel and radioactive waste associated with Russian nuclear submarine dismantlement. A variety of projects address spent nuclear fuel transport and storage, radioactive waste processing, and personnel safety and monitoring.

AMEC projects have been instrumental in changing the Russian nuclear waste storage system from a "wet" system, prone to failure, to a "dry" system used by most Western nations. Storage and transport of Spent Nuclear Fuel – which accounts for 99% of the radioactivity released from radioactive waste while constituting only 5% of the volume – has been improved through the use of the AMEC developed "40 ton cask". This cask is now mass produced as the "TUK MBK 108" and is used by the Cooperative Threat Reduction Program for the Spent Nuclear Fuel from Ballistic Submarines while the Ministry of Atomic Energy uses the casks for the fuel from the General Purpose Submarines. The AMEC temporary storage/transshipment pad at RTP Atomflot will be placed in operation this year – the use of this pad will significantly reduce the transfer of Spent Fuel from service ship to railcar. This will also be the year that a comprehensive radioactive waste treatment and storage complex will be completed at Polyarnskyi, Shipyard 10. This complex will process 500 cubic meters of solid waste annually using the AMEC developed Mobile Pretreatment Facility and special steel transport/storage containers. The containers will be protected from the elements by light-weight storage buildings. Radio-ecological conditions at the site, as well as at the RTP Atomflot pad, will be monitored by the "Picasso" system, another AMEC project. Future plans include the development of a mobile liquid Waste Treatment facility for the site.

In 2000, AMEC funded the Advanced Technology Research Foundation - Russia (ATRP-R) to conduct a technical feasibility study on the ecological safety of dismantling decommissioned Russian nuclear submarines. The report concluded that due to the large number of submarines to be dismantled and the Russian dismantlement process, hazardous conditions for personnel and the environment existed, especially during contingency operations or emergencies. Also, that it is

possible to estimate risk levels during the dismantlement process and to create an unclassified meta-database for further analysis. The Russian Ministry of Defense, Ministry of Atomic Energy and Academy of Sciences endorsed this report. An independent U.S. Review Board provided positive comments and substantiated the necessity for more detailed and comprehensive research. It was agreed to focus this effort on the Northwest region of Russia where the Northern Fleet's decommissioned nuclear submarines and dismantlement facilities are located.

The second AMEC funded ATRP-RU report, again coordinated with Russian Federation government officials was completed in 2002 and a short outline follows:

Chapter1 provides a radio-ecological analysis of the Northern Fleet's decommissioned nuclear submarines and service facilities located on adjacent land and water areas. The conclusions include:

- 50% of the radiation potential in the region comes from the spent nuclear fuel onboard the 50 decommissioned submarines awaiting dismantlement. The poor material condition, lack of maintenance personnel, minimal preventive maintenance and in some cases civilian crews, makes the scenario of "sinking a submarine for safety reasons" not unlikely – supposedly this has already been done in the Pacific Fleet.
- Significant amounts of gas, aerosols and dust is released during dismantling polluting the air, soil and water with non-radioactive substances in the vicinity of the work sites. For example, the gas-plasma arc cutting torches pollute 35 million cubic meters of air with hazardous substances when cutting one ton of steel 20 mm thick. The protective equipment used by the workers is ineffective. Improved ecological monitoring is required.
- Under normal conditions nuclear and radiation procedures will not "worsen the radio-ecological conditions in the region, however, because of the increasing pace of submarine dismantlement operations and the limited storage facilities, there is cause for concern;

Chapter 2 of the report looks at the state of the environment in the vicinity of the decommissioned submarines, dismantlement and storage sites. This includes Zvezdochka, Sevmash, Nerpa, RTP Atomflot, Andreeva Bay and Gremikha. The last two sites are "real" and not "potential" sources of environmental pollution on the Kola Peninsula.

Chapter 3 outlines the concept of ecological safety management including the radio-ecological monitoring of work related to nuclear submarine dismantlement in the Archangelsk and Murmansk regions.

Chapter 4 reviews the Russian legal framework governing nuclear submarine dismantlement at the international, federal, regional and departmental level.

A third AMEC funded ATRP-R report is planned for 2003. This report will focus on Russia's Far East where the Pacific fleet is located.

INTRODUCTION

General Positions

Within the framework of the collaboration between the Advanced Technology Research Foundation (ATRP-R), Russia, and the Department of Defense, USA, a project ATRP-R 1.1 referred to as "Environmental Security Implications of the Decommissioned Russian Nuclear Submarines (Including the Process of their Salvaging) on the Ecological Safety: Analysis of Technical Feasibility of the Project" was completed in 2000 [1]. This was the first project within the framework of the ATRP-R 1 Project dealing with investigations on most urgent ecological problems resulting from Russian nuclear submarine utilization.

In the process of the project report [1] creation, over 30 experts from various institutes and enterprises of the Russian Academy of Sciences, Minatom and Ministry of Defense of Russia, Russian Shipbuilding Agency (Rossudostroenye) and other departments were involved. The list of authors is presented at the end of the report.

In the course of that investigation, a number of important conclusions were reached, which substantiated the necessity for more detailed and comprehensive research on ecological safety issues in regions involved in large-scale handling of Russian nuclear submarines after decommissioning.

In particular, the following statements were made:

- The large scale of work related to the process of handling nuclear submarines after decommissioning and the distinctive features of the Russian model of their handling create a background of real hazards for both the environment and the personnel, especially in cases of contingency or emergency.

- The problem of safety when handling nuclear submarines after decommissioning from the Navy would remain urgent for a long period of time. This is due to the important number of units to be utilized, as well as the large quantities of spent fuel, liquid and solid radioactive wastes accumulated within Northwest and Far-East regions of Russia, thus giving no expectation for the rapid solution of the problem.
- Materials systematized in the report, including a meta-database of declassified data (under creation) represented a sufficient basis to carry out subsequent investigations. This work would include quantitative risk estimations at all stages of nuclear submarine handling after their decommissioning from the Navy and the development of procedures and actions aimed at decreasing these risks.
- Investigations to be performed would make it possible:
  - to estimate real risk levels resulting from nuclear submarine handling after decommissioning,
  - to determine necessary organizational and scientific and technical solutions for their minimization,
  - to promote the formation of supportive public opinion in Russia and other countries when considering such an important ecological problem.

When preparing further development of the work started in 2000 within the framework of ATRP-R 1 Project, it was agreed that in 2001 the problem of ecological safety during the process of nuclear submarine utilization (ARTP 1.2 Project) [2] would be studied only within the Northwest region of Russia (ATRP-R 1.2.1 Subproject). The following lines of this part of work were accepted as basic ones:

- analysis of the state (including the radioecological state) of all decommissioned nuclear submarines in the Northern Fleet as well as of other nuclear-powered units and installations of the region forming their supporting infrastructure;
- analysis of the radioecological state of territories and water areas wherein (or close to which) units and installations involved in the handling process are located, i.e., plants, coastal servicing enterprises, repositories containing spent fuel, liquid radioactive wastes and solid radioactive wastes;
- development of a concept of the ecological safety management including the radioecological monitoring of work related to nuclear submarine handling after the decommissioning in Arkhangelsk and Murmansk regions;
- analysis of the existing standard and legal acts dealing with the handling of nuclear submarines and spent fuel at different (international, federal, regional and departmental) levels;
- substantiation of a list of projects within the framework of ATRP-R 1 Project for 2002-2005.

It was also agreed that the PS tasks of ATRP-R 1.2 Project remained outside the ATRP-R 1.2.1 Subproject (e.g.: 1 – Analysis of the Ecological State of Units and Installations in the Far East

Region; 2 – Analysis of the Ecological State within the Concerned Territories in the Far East Region, et al.) and that these would be considered later upon agreement between the Parties.

When preparing the present report for the ATRP-R Project 1.2.1, the remarks made by the US Review Panel independent organization [3] related to ATRP-R Report–2000 were taken into account most carefully. In particular, special attention has been concentrated on issues of non-radioactive environment contamination being created in the process of nuclear submarine handling after decommissioning, as well as correct translation concerns.

Peculiarities of the Radioecological Situation in Northwest Region of Russia

The Northwest region of the Russian Federation occupies an area of 1,677,000 km^2 in the North and the Northwest parts of East Europe, making up about 10 percent of all the territory of Russia. It includes seven administrative regions (Murmansk, Arkhangelsk, Vologda, Leningrad, Novgorod, Pskov and Kaliningrad regions) and two (Karelia and Komi) republics.

The radiation situation in any region of developed industry is determined by the following two components: the natural radiation background (NRB) and the human-caused radiation constituent technogenic effects (TE).

The analysis presented below of the radiation situation within Northwest region of Russia was carried out with the participation of V.V. Dovgusha, I.V. Lisovskiy and other experts of ATRP-R Project 1.2.1. [3]; the monographs listed in [4] were also used.

The natural radiation background results from both the cosmic irradiation and the natural radionuclide irradiation. On average, natural ionizing radiation sources (IRS) are responsible for up to 70 perecent or even more of the integral dose obtained by human beings from all IRS. However, this is true for regions with small concentrations of man-made IRS. In Northwest region, the human-caused IRS constituent becomes more and more important. This is mainly due to the presence of atomic fleet units and installations of their supporting infrastructure.

Hazards resulting from NRB can be estimated as follows: according to the present-day outlook, the dose of 1 mSv increases the risk of diseases with fatal consequences by $6.3 \cdot 10^{-5}$. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) estimations, the annual effective dose equivalent due to natural IRS makes up about 2.4 mSv per capita. The dose of 2.4 mSv/year increases the risk by $1.4 \cdot 10^{-4}$ /year or by 0.01 during 70 years. This means that, on average, one person (out of 100 persons) dies untimely due to cancer and hereditary effects induced by NRB.

As with all IRS, the natural radiation background results in both external and internal human exposure. The external exposure depends on the content of natural radioactive elements in the environment, primarily in the lithosphere. The largest contributions are due to uranium and its daughters, thorium and its daughters and also potassium-40.

External exposure is created by natural radionuclides distributed within the upper layer of soil and rocks. The thickness of radionuclide layers depends on their composition and density and varies from 15-20 to 30-50 cm.

Soils inherit radio-geochemical features of the ground located below and concentrate 70 to 80 percent of radioactive elements. However, the distribution of natural radioactive elements over the soil depends in large measure on geochemical peculiarities of the landscape zonality resulting from the impact of solar irradiation on the Earth surface.

In Figures 1.1.1 through 1.1.3 concentrations of uranium, thorium and potassium in Northwest region of Russia are depicted. It is obvious that soil radionuclides are transferred into biota: directly in plants and via food chains and trophic pyramids in animals. The following pattern is observed: ^{40}K balance in human organisms remain constant but at the same time radium and its daughters can accumulate via ingestion. Earth-borne radionuclides create annual effective dose of about 1400 μSv for the human organism.

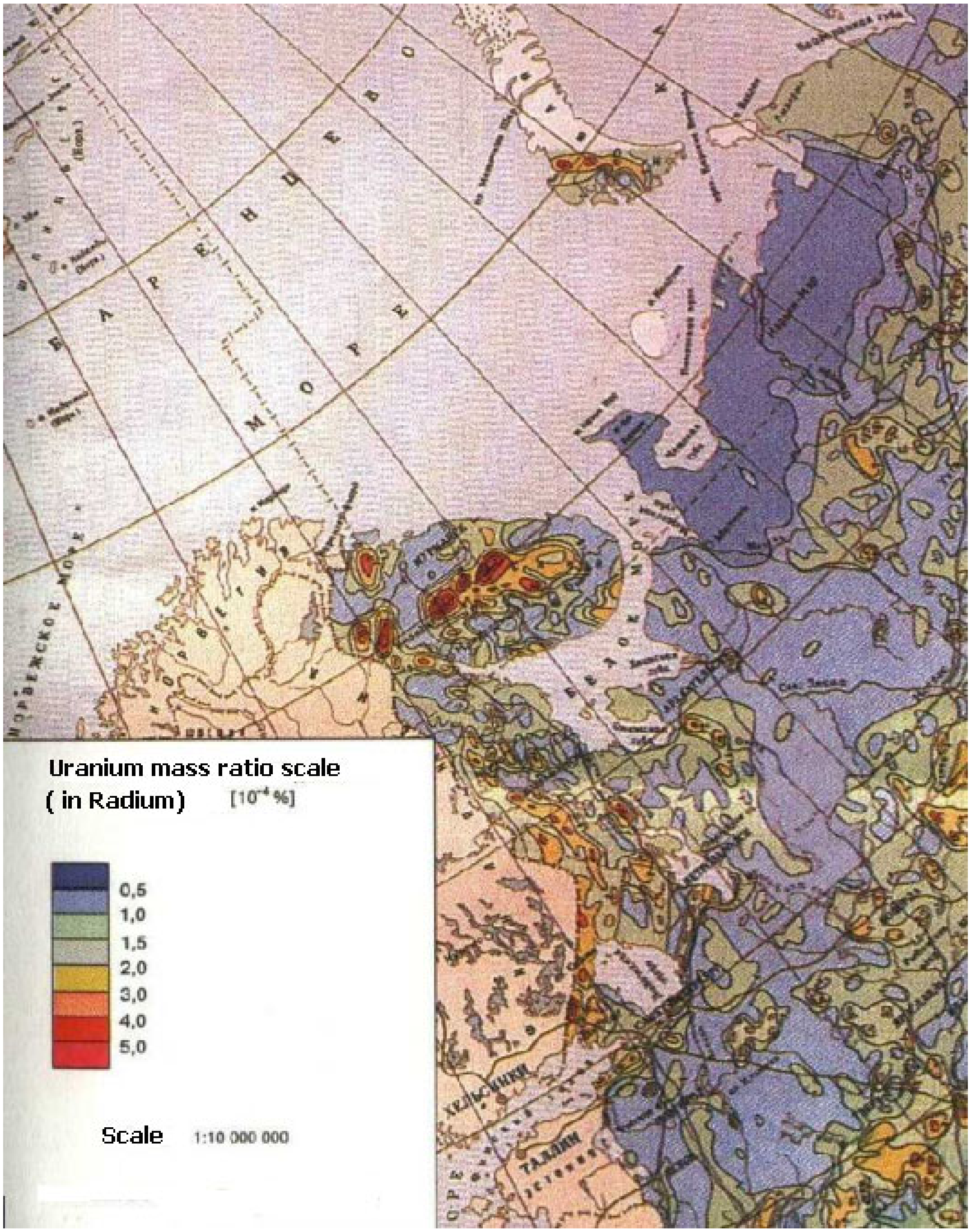

Fig.1 Uranium concentrations in Northwest region of Russia

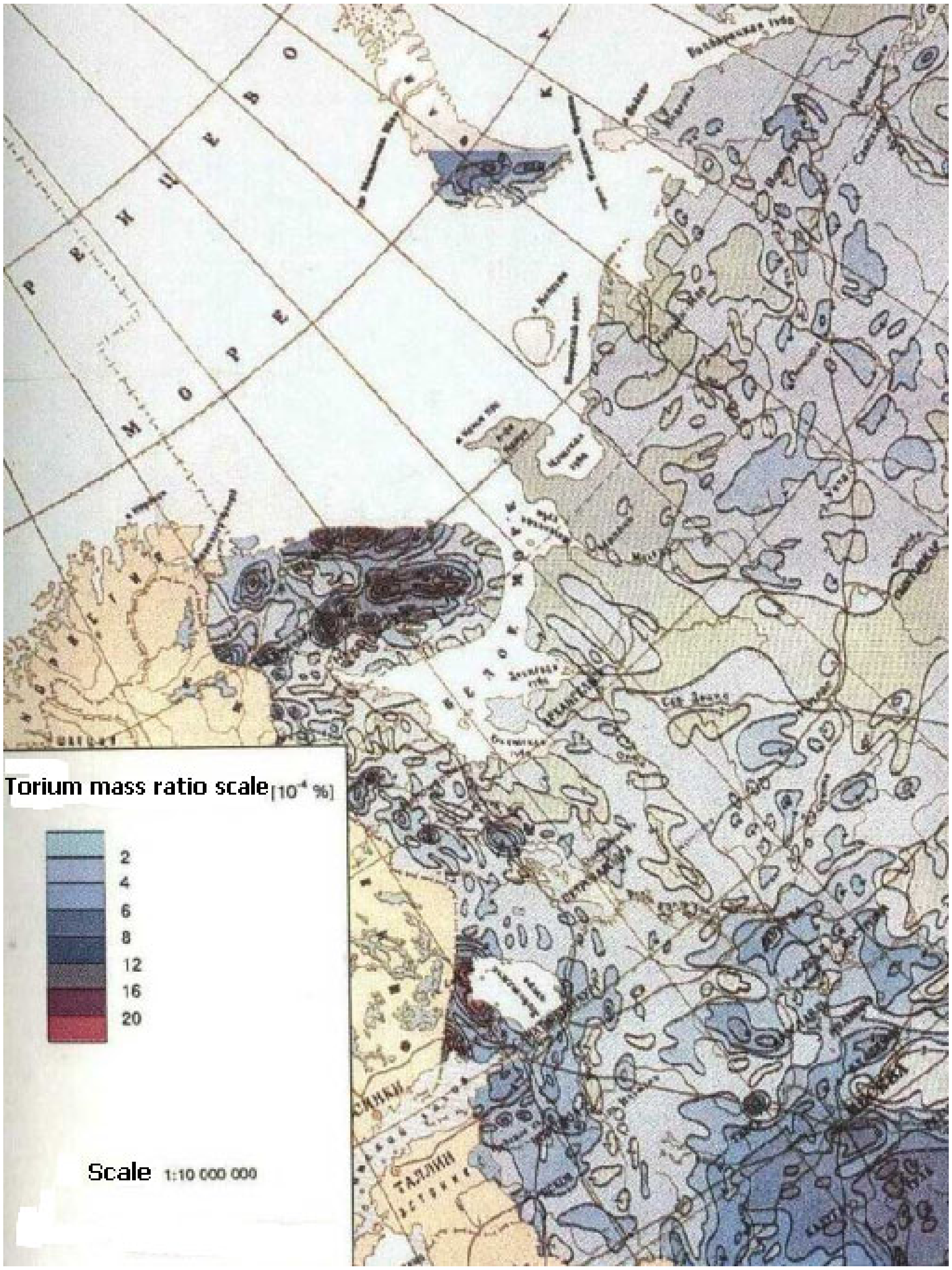

Fig. 2 Thorium concentrations in Northwest region of Russia

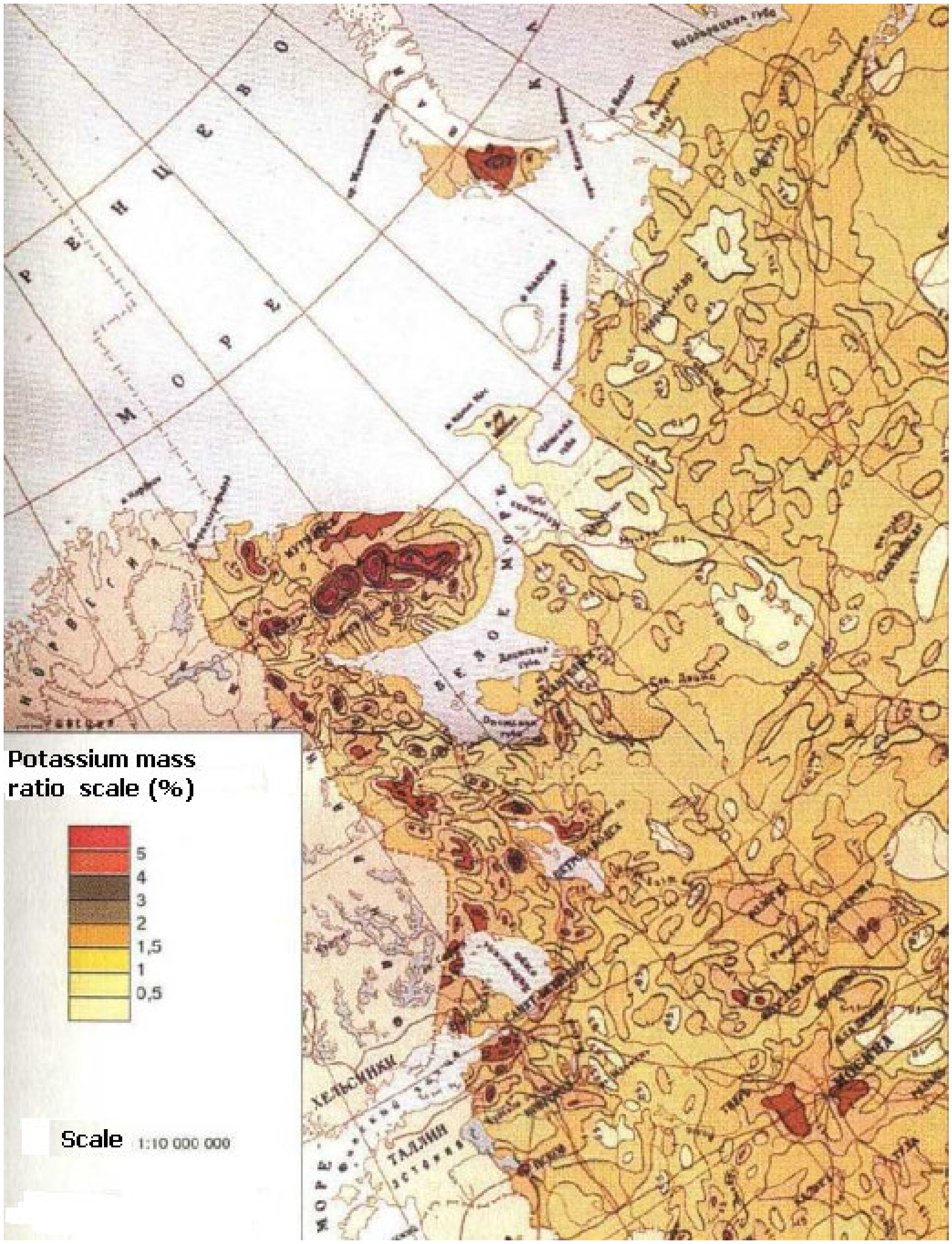

Fig. 3 Potassium concentrations in Northwest region of Russia

Natural Radioactive Element Deposits

Within the region considered there are several locations of developing uranium and ore mineralization (deposits). The integral prospected resources in natural radioactive elements make up 5000 to 20 000 t.

The annual human exposure dose due to natural IRS is equal to 2.2 mSv on average. This value includes: 1.0 mSv/year from indoor radon, 0.5 mSv/year from gamma-irradiation of natural radionuclides (NRN) of grounds and building materials, 0.4 mSv/year from NRB intake via ingestion and 0.3 mSv/year due to cosmic irradiation. With the exception of radon, levels of natural background components differ from the average value over the Earth's territories by a factor of two at the most. The dose rate (DR) of external gamma-irradiation indoors makes up 8-20 μR/h (doses of 0.4 to 1.0 mSv/year) and rarely exceeds a control level now in force in Russia (33 μR/h above the gamma background in open air). Most of the dose from natural radiation sources is due to radon created by the decay of radioactive sequences.

Depending on the dose from radon, the population exposure (mean effective dose value) during 70 years within the Northwest part of Europe varies from 0.2 to 1.5 Sv (note that the exposure within the most radon-dangerous territories exceeds the "normal" exposure level by more than 1 Sv). The exposure value of small population groups can exceed the average value by dozens of times. The collective dose of the population in Russia resulting from natural IRS is equal to 50 million pers.-rem/year. This value exceeds the collective dose obtained by the Russian population as a result of the Chernobyl accident by more than 300 times. As expected, the incidence of oncological diseases and genetic effects increases proportionally with collective dose value.

The largest contribution to the population exposure due to natural radiation background results from radon and products of its decay in the air. The radon content in air depends on: - its concentration in soils and the subsurface and their emanating characteristics; - its concentrations in building materials and their emanating characteristics; and - features of building construction.

The radon volumetric activity in air makes up 40 Bq/m^3 on average (the corresponding dose is equal to 6 mSv/year). An increase of lung cancer incidence with fatal consequences represents the gravest result of radon exposure. The dose of 1 mSv contributes to an increase of the risk of oncological disease with fatal consequences by $5 \cdot 10^{-5}$. Thus, the dose of 2.2 mSv/year increases the risk by $1.1 \cdot 10^{-4}$ person/year or by $8 \cdot 10^{-3}$ during 70 years of life.

Within the Northwest region of Russia the areas of greatest radon-danger probability refer to Karelia granites and outcrops of igneous rocks in the Kola Peninsula, as well as radium-bearing waters and outcrops of sedimentary (including metamorphized) rocks. The latter are limestone of the Rogachev series (New Land), near-glint part of the Dictionem slate stratum and bauxite outcrop areas in Leningrad and Novgorod regions. As the result of a relatively minor investigation, several most dangerous territories (from the point of view of natural IRS) have been identified within Northwest region of Russia. Among them St. Petersburg, Leningrad region (Gatchina, Vyborg), Ukhta, Petrozavodsk town, et al., can be listed.

As a whole, from the point of view of the “radon” factor, the radiation situation within the Northwest region of Russia is far from safe. It differs considerably from average Russian and world indices (where mean equivalent equilibrium volume activity of radon makes up 25 Bq/m^3 and the number of buildings in excess of the norm is equal to 1 to 2 percent at the most at dose equivalent of 2.4 mSv/year).

The situation related to IRS in the region under consideration is further complicated by additional circumstances. Within this territory two important Nuclear Power Plants (NPP) are located (Sosnovy Bor NPP and Kola NPP). Moreover, along the Kola Peninsula shore a considerable amount of nuclear-powered units and installations, which belong to both the Russian Atomic Navy and Civil Fleet, are dispersed. In addition to coastal and floating enterprises providing nuclear vessel servicing, over 120 nuclear vessels (of different life cycle stages) of the Navy and eight surface ships with power reactor facilities of Murmansk Sea Navigation Enterprise are located in the region.

It is well known that many nuclear weapons tests were performed in the Novaya Zemlia (New Land) archipelago, and considerable amounts of radioactive wastes were dumped into the water area around the islands (Figures 4 - 6).

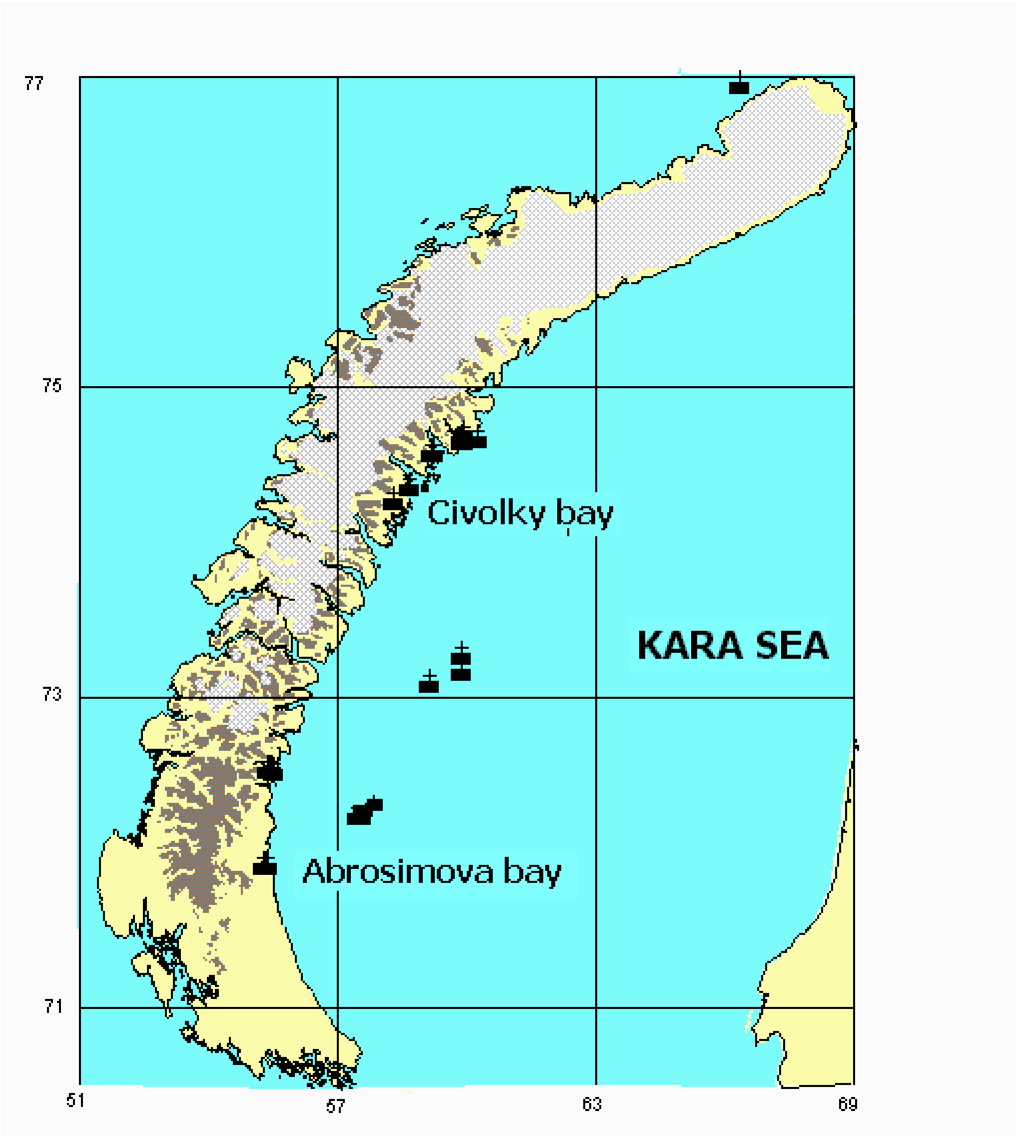

Fig. 4 Dumped Radioactive Wastes in Kara Sea.

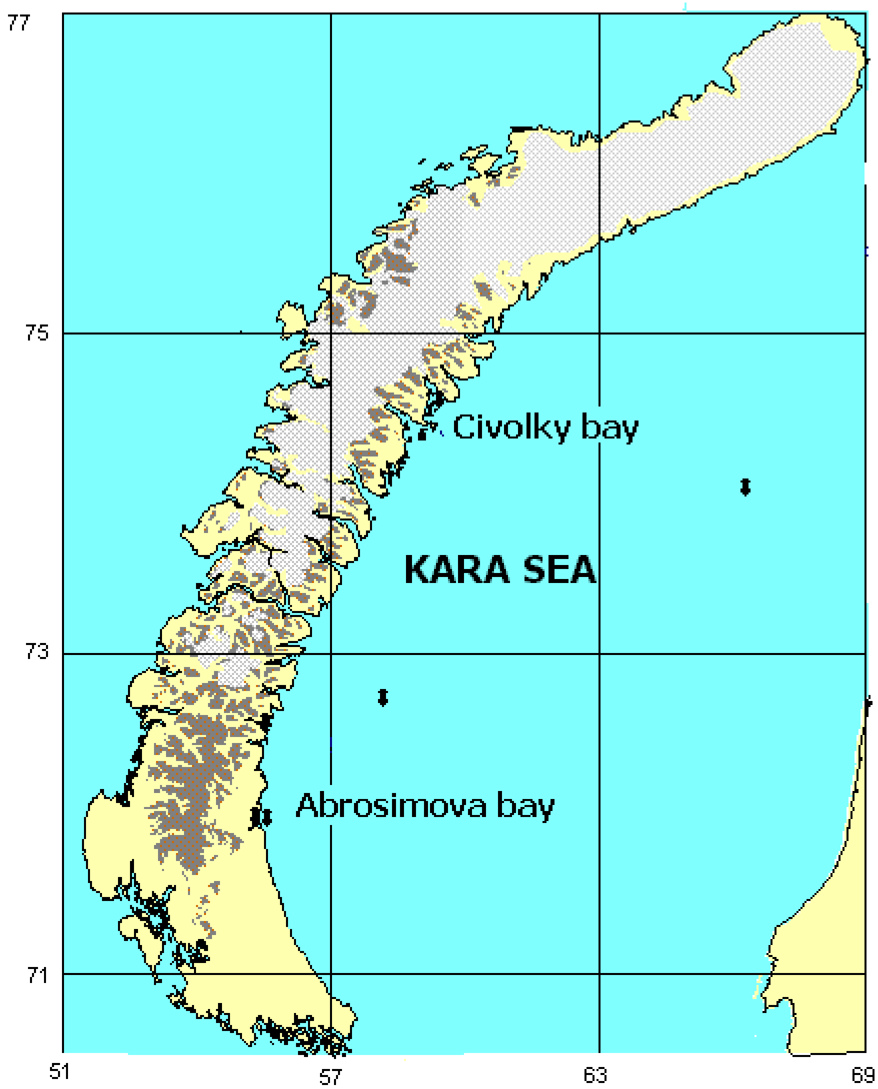

Fig. 5 Submerged Reactors in Kara Sea.

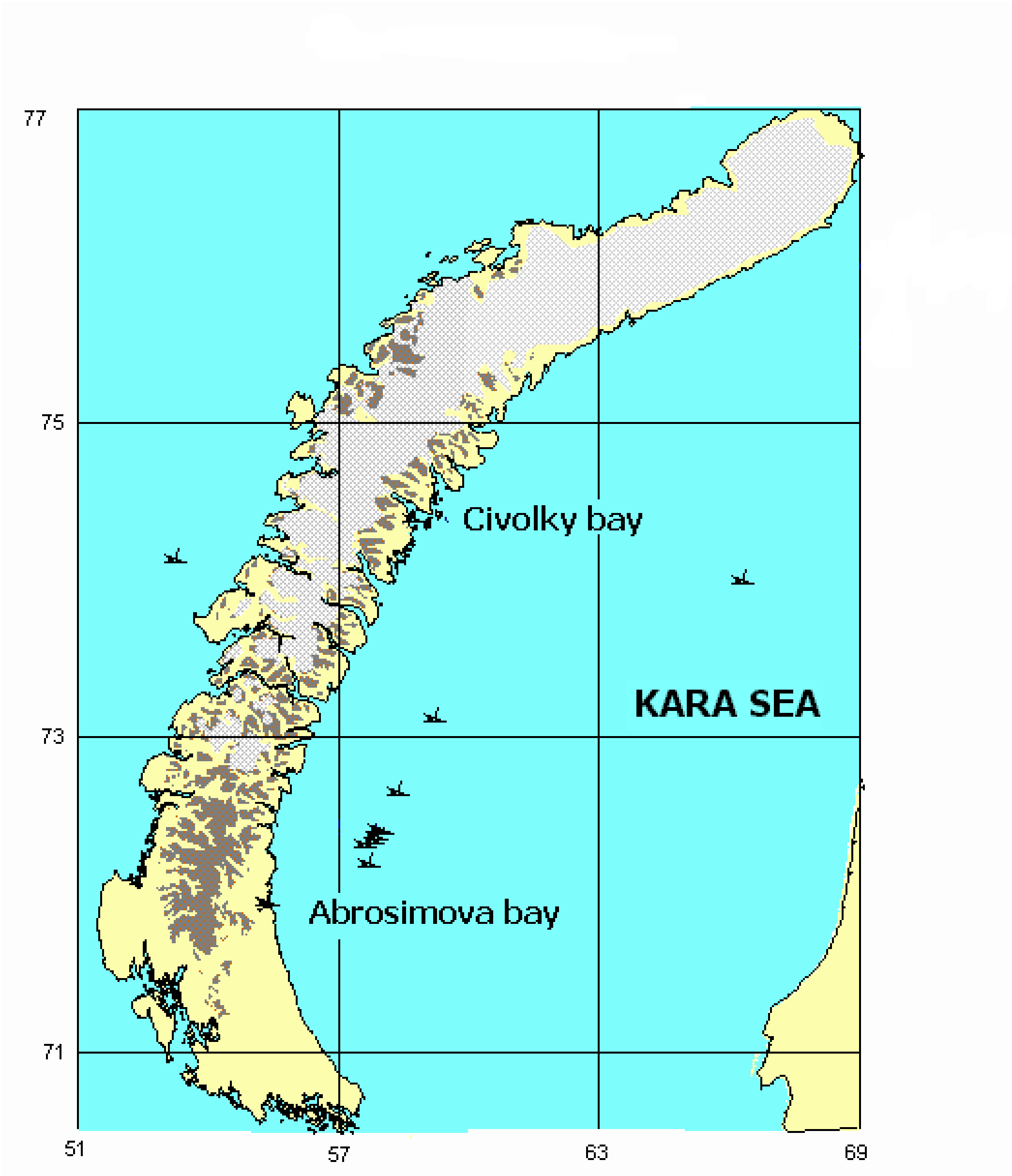

Fig.6 Submerged Vessels in Kara Sea.

Since the onset of work dealing with nuclear submarine handling after decommissioning, the number of operations related to spent fuel unloading from vessel reactors as well as volumes of spent fuel, liquid and solid radioactive waste temporarily stored in the region have grown considerably. As a result, the man-made component of radiation exposure also increased. These circumstances require more careful control and analysis. In turn, the risk of initiating off-normal and emergency situations in the region when storing nuclear submarines with spent fuel in afloat conditions and when transporting and handling spent fuel, liquid and solid radioactive wastes rises too. The data generalized in the given report constitute both a necessary base of data and a basis for further study of quantitative indices of hazards and risks at different stages of the Arctic Navy nuclear submarine handling after decommissioning. They also form a basis for a system of ecological safety management when carrying out such a large-scale work.

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1. Analysis of the Radioecological State of Units and Installations Dealing with Nuclear Submarine Handling after the Decommissioning

1.1. List and Characteristics of Nuclear Powered Units and Radioactive Material Handling Installations

The nuclear powered units and radioactive material handling installations to be involved in the process of nuclear submarine utilization in Northwest region of Russia include:

- 115 nuclear submarines (NS) & reactor units under waterborne storage;
- 3 Floating Servicing Enterprises (FSE), design 2020;
- 6 Technological Tankers (TT);
- 3 Floating Control-Dosimetric Moorings (FCDM);
- 9 floating tanks for LRW;
- 8 Floating Service Enterprise (FSE), designs 326, 326M;
- 2 Coastal Servicing Enterprises (CSE);
- 6 shipbuilding and ship-repair enterprises (yards).

1.1.1. Decommissioned Nuclear Submarines of the Arctic Navy

Table 1.1. List of Decommissioned Nuclear Submarines of the Arctic Navy (as of January 01, 2002)

№	Serial number	NATO classification	Reactor shutdown date	Spent fuel unloading date	Reactor unit creation date comp=compartment	Location
1.	283	November	1986	1996	4-comp.; 1996	Saida Gulf
2.	287	November	1983	1989	9-comp.; 1990	Saida Gulf
3.	254	November	1987	With SF	-	Ostrovnoy town
4.	289	November	1988	With SF	-	Ostrovnoy town
5.	260	November	1989	1996	4-comp.; 2000	Saida Gulf
6.	284	November	1989	With SF	-	Ostrovnoy town
7.	285	November	1989	2001	4-comp.; 2001	10th Navy SRY
8.	291	November	1990	With SF	-	Ostrovnoy town
9.	904	Hotel	1984	1991	10-comp.; 1990	Saida Gulf

№	Serial number	NATO classification	Reactor shutdown date	Spent fuel unloading date	Reactor unit creation date comp=compartment	Location
10.	902	Hotel	1987	With SF	-	Ostrovnoy town
11.	905	Hotel	1987	1992	10-comp.; 1992	Saida Gulf
12.	901	Hotel	1987	With SF	-	Ura Gulf
13.	907	Hotel	1989	With SF	-	Ara Gulf
14.	540	Echo-II	1988	1991	8-comp.; 1991	Saida Gulf
15.	545	Echo -II	1987	1998	3-comp.; 2000	Saida Gulf
16.	530	Echo -II	1989	2001	-	«Nerpa» SRY
17.	531	Echo -II	1990	With SF	-	10th Navy SRY
18.	533	Echo -II	1990	1999	10-comp.; 2000	Saida Gulf
19.	536	Echo -II	1985	1990	10-comp.; 1992	Saida Gulf
20.	543	Echo -II	1989	With SF	-	Ura Gulf
21.	532	Echo -II	1990	With SF	-	«Nerpa» SRY
22.	542	Echo -II	1990	With SF	-	Ara Gulf
23.	535	Echo -II	1991	With SF	-	Ara Gulf
24.	537	Echo -II	1990	With SF	-	Ara Gulf
25.	539	Echo -II	1992	With SF	-	Ara Gulf
26.	534	Echo -II	1994	2001	-	10th Navy SRY
27.	538	Echo -II	1994	2001	-	35th Navy SRY
28.	544	Echo -II	1994	2001	-	«Nerpa» SRY
29.	902	Charley-II	1988	2000	3-comp.; 2001	Saida Gulf
30.	903	Charley -II	1989	1994	3-comp.; 1996	Saida Gulf
31.	904	Charley -II	1991	2000	3-comp.; 2001	Saida Gulf
32.	905	Charley -II	1995	2000	3-comp.; 2001	«Nerpa» SRY
33.	911	Charley -II	1993	2001	-	«Nerpa» SRY
34.	901	Charley -II	1995	2000	3-comp.; 2001	Saida Gulf
35.	600	Victor-I	1991	With SF	-	Ostrovnoy town
36.	601	Victor -I	1990	With SF	-	Ostrovnoy town
37.	604	Victor -I	1990	With SF	-	Ostrovnoy town
38.	615	Victor -I	1990	1994	1-comp.; 1995	Saida Gulf
39.	603	Victor -I	1992	With SF	-	Ostrovnoy town
40.	605	Victor -I	1993	With SF	-	Ostrovnoy town
41.	606	Victor -I	1993	With SF	-	Ostrovnoy town
42.	613	Victor -I	1992	With SF	-	Ura Gulf

№	Serial number	NATO classification	Reactor shutdown date	Spent fuel unloading date	Reactor unit creation date comp=compartment	Location
43.	621	Victor -II	1991	With SF	-	Ura Gulf
44.	625	Victor -II	1993	With SF	-	Ostrovnoy town
45.	804	Victor -II	1988	2000	-	10th Navy SRY
46.	627	Victor -II	1992	With SF	-	Ostrovnoy town
47.	609	Victor -I	1994	With SF	-	Ostrovnoy town
48.	608	Victor -I	1995	With SF	-	Ostrovnoy town
49.	611	Victor -I	1995	With SF	-	Ostrovnoy town
50.	801	Victor -II	1995	With SF	-	Ostrovnoy town
51.	802	Victor -II	1996	2000	-	10th Navy SRY
52.	602	Victor -I	1997	With SF	-	Ostrovnoy town
53.	803	Victor -II	1989	1999	3-comp.; 2001	Saida Gulf
54.	906	Hotel	1988	1993	10-comp.; 1993	Saida Gulf
55.	900	Alpha	1972	With SF	1- comp.; 1986	Saida Gulf
56.	905	Alpha	1987	1990	1-comp.; 1995	Saida Gulf
57.	106	Alpha	1989	1993	1- comp.; 1996	Saida Gulf
58.	910	Alpha	1989	With SF	-	B. Lopatka Bay
59.	107	Alpha	1989	1991	1- comp.; 1997	Saida Gulf
60.	915	Alpha	1989	1992	1-comp.; 1994	Saida Gulf
61.	105	Alpha	1996	With SF	-	B. Lopatka Bay
62.	б/н	Alpha	1983	With SF	1-comp.; 1984	Saida Gulf
63.	501	Papa	1986	With SF	-	FSUE “Sevmash PA”
64.	512Э	Juliett	1991	With SF	-	Ura Gulf
65.	638	Victor-III	1992	2001	-	10th Navy SRY
66.	301	Victor -III	1991	2001	-	«Nerpa» SRY
67.	645	Victor -III	1994	With SF	-	Ura Gulf
68.	647	Victor -III	1992	2001	-	10th Navy SRY
69.	652	Victor -III	1993	With SF	-	Ura Gulf
70.	296	Victor -III	1996	With SF	-	Ura Gulf
71.	297	Victor -III	1996	With SF	-	Ura Gulf
72.	649	Victor -III	1996	With SF	-	Ura Gulf
73.	641	Victor -III	2000	With SF	-	B. Lapatkina Bay
74.	636	Victor -III	2000	With SF	-	B. Lapatkina Bay
75.	643	Victor -III	2001	With SF	-	B. Lapatkina Bay

№	Serial number	NATO classification	Reactor shutdown date	Spent fuel unloading date	Reactor unit creation date comp=compartment	Location
76.	424	Yankee	1985	1993	8-comp.; 1993	Saida Gulf
77.	422	Yankee	1981	1991	8-comp.; 1991	Saida Gulf
78.	402	Yankee	1984	1992	8-comp.; 1992	Saida Gulf
79.	401	Yankee	1984	1995	3-comp.; 1996	Saida Gulf
80.	400	Yankee	1981	2001	3-comp.; 2001	«Zvezdochka» SMBE
81.	431	Yankee	1988	1997	3-comp.; 1997	Saida Gulf
82.	423	Yankee	1986	1996	3-comp.; 1997	Saida Gulf
83.	441	Yankee	1989	2001	-	«Zvezdochka» SMBE
84.	421	Yankee	1989	1995	3-comp.; 1996	Belomorskaya NB
85.	452	Yankee	1986	1996	3-comp.; 2000	Saida Gulf
86.	462	Yankee	1990	1993	3-comp.; 1993	Saida Gulf
87.	451	Yankee	1991	1993	3-comp.; 1994	Saida Gulf
88.	470	Yankee	1991	1991	3-comp.; 1995	Belomorskaya NB
89.	414	Yankee	1991	With SF	-	«Nerpa» SRY
90.	461	Yankee	1992	1994	3-comp.; 1995	Ostrovnoy town
91.	420	Yankee	1992	With SF	-	Belomorskaya NB
92.	432	Yankee	1993	With SF	-	Jaguel’naya Gulf
93.	440	Yankee	1994	With SF	-	«Nerpa» SRY
94.	310	Delta-I	1990	2001	-	«Zvezdochka» SMBE
95.	312	Delta -I	1992	1996	3-comp.; 1997	Saida Gulf
96.	326	Delta -I	1994	1997	3-comp.; 1998	Saida Gulf
97.	337	Delta -I	1993	1999	3-comp.; 1999	Saida Gulf
98.	339	Delta -I	1994	1999	3-comp.; 1999	Saida Gulf
99.	338	Delta -I	1993	1999	3-comp.; 1999	Saida Gulf
100.	324	Delta -I	1991	2001	-	«Zvezdochka» SMBE
101.	325	Delta	2001	2001	-	“Nerpa” SRY
102.	341	Delta-II	1995	2000	3-comp.; 2000	Saida Gulf
103.	354	Delta -II	1993	1999	3-comp.; 1999	Saida Gulf
104.	353	Delta -II	1993	1997	3-comp.; 1998	Saida Gulf
105.	342	Delta -II	1993	2000	3-comp.; 2000	Saida Gulf
106.	355	Delta -III	1994	2000	3-comp.; 2000	Saida Gulf
107.	373	Delta -III	1995	2000	3-comp.; 2000	«Zvezdochka» SMBE
108.	712	Typhoon	1993	With SF	-	FSUE “Sevmash PA”

№	Serial number	NATO classification	Reactor shutdown date	Spent fuel unloading date	Reactor unit creation date comp=compartment	Location
109.	713	Typhoon	1994	With SF	-	Nerpichia Bay
110.	724	Typhoon	1997	With SF	-	Nerpichia Bay
111.	3001	Shark	1992	With SF	-	«Zvezdochka» SRY
112.	605	Oscar	1990	2000	-	FSUE "Sevmash PA"
113.	606	Oscar	1991	2001	-	FSUE "Sevmash PA"
114.	617	Oscar	1996	With SF	-	B. Lopatka Bay
115.	662	Oscar	2000	With SF	-	82nd Navy SRY

Comments to Table 1.1.

1. Three-compartment reactor unit is a reactor compartment with two adjacent compartments.
2. Four-compartment unit is a reactor compartment with three adjacent compartments.
3. Multi-compartment (8-10 compartments) unit represents a nuclear submarine with cut out missile shafts.

Thus, out of 115 NS decommissioned from the Arctic Navy, 51 NS are stored "afloat" with cores, and three-unit compartments have been removed from 48 NS. Sixteen NS are in preparation.

1.1.2. List of Nuclear Maintenance Support Vessels (NMS Vessels or NMSV)

At the present time, both the Arctic Navy and the Murmansk Sea Navigation Enterprise have 29 vessels involved in the process of nuclear submarine dismantling as well as spent fuel and radioactive waste handling [1.35, 1.94]. In Table 1.2 their technical characteristics and location areas are presented.

Table 1.2. Characteristics of Nuclear Maintenance Support Vessels

Name	Location	Purpose	Integral tank volume, m^3
Floating servicing enterprises			
PM-12	Snezhnogorsk-1, Olen'ja Gulf	LRW & SRW	267.0
PM-50	Snezhnogorsk-1, Olen'ja Gulf	LRW & SRW	307.6

Name	Location	Purpose	Integral tank volume, m^3
PM-78	Snezhnogorsk-1, Olen'ja Gulf	LRW & SRW	308.4
PM-128	Snezhnogorsk-1, Olen'ja Gulf	LRW & SRW	255.8
PM-63	Severodvinsk	LRW & SRW	899.2
PM-124	Severodvinsk	LRW & SRW	185.2
Tankers			
TPT-29	Iokan'ga region, Ostrovnoj-town	LRW	910.64
TPT –12	Snezhnogorsk-1, Olen'ja Gulf	LRW	906.0
TPT –19	Snezhnogorsk-1, Olen'ja Gulf	LRW	906.0
TPT "Amur"	Snezhnogorsk-1, Olen'ja Gulf	LRW	Is not ready to accept LRW
TPT –25	Severodvinsk	LRW	984.93
TPT "Ossetija"	Severodvinsk	LRW	1033
Control Dosimetric Stations (CDS)			
FCDM –49	Poliarny-town	LRW	40.0
FCDM –9	Poliarny-town	LRW	80.0
FCDM –14	Poliarny-town	LRW	50.0
Total: LRW 131.3m^3 (41.3m^3 – Arctic Navy)			
Floating tanks			
FT-50	Zaozersk-town	LRW	50
FT-50	Zaozersk-town	LRW	50
FT-50	Skalisty-town	LRW	50
FT-50	Skalisty-town	LRW	50
FT-50	Ura Gulf of Vidiaevo region	LRW	50
FT-50	Ura Gulf of Vidiaevo region	LRW	50
FT-50	Vil. Rosta	LRW	50
FT-50	SRY "Nerpa" of Snezhnogorsk-town	LRW	50
FT-50	SRY "Nerpa" of Snezhnogorsk-town	LRW	50
FSE «Imandra»	Murmansk	LRW	545
FSE «Lepse»	Murmansk	-	1630/60
FSE «Lotta»	Murmansk	-	-
FSE «Volodarskij»	Murmansk	-	-
FSE Tanker	Murmansk	LRW	1151

Name	Location	Purpose	Integral tank volume, m^3
«Severianka»			

1.1.3. Coastal Servicing Enterprises (CSE) and Repositories of Spent Fuel (SF) and Radioactive Wastes (RW)

Work on handling of nuclear submarines after decommissioning, as well as SF & RW handling (including storage) are carried out within different types of coastal installations in the Northwest region. A complete list of such installations is presented in Table 1.3 (location area, and basic characteristics are also indicated) [1.32, 1.34, 1.35].

Table 1.3. Characteristics of CSE of the Northwest Region

№	Installation Name	Location	Purpose
1.	Coastal Servicing Enterprise (CSE)	Murmansk region, Andreeva Bay	Storage of non-irradiated and spent fuel, reactor recharge, activity filter reloading, washing of working clothes, decontamination of individual protectants, LRW treatment, SRW collection and storage, special equipment use and repair.
2.	CSE	Murmansk region, Gremikha village	Collection, storage, transportation of SF and RW (LRW & SRW), nuclear fuel recharge of submarines with PWR and liquid-metal reactors, use and repair of special equipment, repair of nuclear vessels in docks.
3.	Ship-repair yard of Poliarny	Murmansk region, Poliarny-town	Repair of all types of nuclear vessels and diesel-power nuclear submarines, nuclear submarine dismantling, attendant nuclear submarine reactor reloading work, collection, temporary storage & transportation of RW.
4.	«Nerpa» Shipyard	Murmansk region, Snezhnogorsk-town, Kut Gulf of Kola Bay	All kinds of repair of multi-purpose nuclear submarines, attendant work on nuclear fuel recharge, NS dismantling, RW storage and transportation, building & repair of civil vessels.
5.	«Zvezdochka» State Machine-Building Enterprise (SMBE)	Arkhangelsk region, Severodvinsk	Repair and utilization of strategic-purpose NS, attendant work on nuclear fuel recharge, RW handling.
6.	Murmansk Shipyard	Murmansk	Repair and modernization of nuclear vessels, NS handling after the decommissioning, RW handling.
7.	SRE «Atomflot»	Murmansk	Maintenance work and repair of nuclear vessels and NMS vessels; reactor equipment repair; collection, temporary storage and reprocessing of SRW & LRW; storage and transportation of non-irradiated and spent fuel; repair and storage of special equipment.
8.	FSUE “Sevmash PA”	Arkhangelsk region, Severodvinsk	NS construction and repair, collection and temporary storage of non-irradiated and spent fuel, RW handling.

1.2. Radiation Potential of Nuclear Submarines and Reactor Units

1.2.1. Radiation Sources of the Decommissioned Nuclear Submarines to Be Dismantled

During the period 1958 to 1991, 232 nuclear submarines were built in the USSR. In the course of 1992 to 2000, 12 nuclear submarines were constructed in the Russian Federation. Three generations of nuclear submarines were created. Altogether, over 140 nuclear submarines were based in the Arctic Navy [1.1, 1.3, 1.5,1.8].

The first-generation nuclear submarines were equipped with two-reactor power facilities of BM-A-type with PWR of 70 Mw heat power. They represented installations with a multi-branch network of the primary circuit pipelines and isolating devices. In the course of their operation, coolant leakage as well as steam generator leaks occurred quite often. It is in the first-generation nuclear submarines that all major nuclear vessel accidents accompanied by severe radiological and radioecological consequences took place.

The second-generation nuclear submarines possess safer block type nuclear power facilities (OK-300, OK-350, OK-650, OK-700). They represent a single unit, which consists of a reactor and steam generators hung via short ducts (“pipe-in-pipe”- mode).

The biological protection of power reactor facilities of both the first and second generation is calculated from an annual maximum permissible dose of 150 mSv/15 rem. Since 1983, the maximum permissible dose of 50 mSv/5 rem has been set for third-generation nuclear submarine personnel. At the present time, the possibility of realizing the requirements of Radiation Safety Standards-99 (RSS-99) related to the fourth-generation nuclear submarines is under study. According to this document, the annual dose limit for A-group personnel equals 20 mSv/2 rem on average in the course of any five consecutive years with a maximum annual limit of 50 mSv/5 rem [1.83].

Figure. 1.1. A Third-generation Nuclear Submarine (Design 971)

Power facilities of the majority of the second-generation nuclear submarine designs also consisted of two reactors. In the 670-design nuclear submarine of the second-generation, single-reactor power facilities were installed. A single-reactor unit was also mounted in 685-design custom-built nuclear submarines («К-278» and «Komsomolets») and in liquid-metal coolant nuclear submarines of 705 and 705К design.

Liquid-metal coolant reactors were developed simultaneously with those of PWR-type. The first liquid-metal coolant nuclear submarine («К-27», Serial number 601, Design 645) was equipped with two reactors. This experimental nuclear submarine was in operation during the period of 1963 to 1968. After the power reactor facility accident on the 24th of May 1968, the submarine was decommissioned and included into the Navy reserve. After necessary preparative operations, in 1981 the submarine was sunk in the vicinity of Novaya Zemlia archipelago (see Figure 5).

Subsequently, liquid-metal coolant reactors were used in a small nuclear submarine series of 705 and 705К design. They were equipped with a single-reactor power facility of ОК-550 and БМ-40А-type. Altogether, seven nuclear submarines of these designs were made. The first nuclear submarine of 705-design was put into operation by the end of 1977. After operational tests, one nuclear submarine of this design («К-47», serial number 900) was dismantled. Its stern containing the core with fuel is stored temporarily in «Zvezdochka» enterprise (Severodvinsk town). In «К-123» (serial number 105), the reactor compartment containing a damaged reactor was replaced. The cut out compartment is stored within a water area of decommissioned nuclear submarine storage of the Arctic Navy in Saida Bay, the Barents Sea. At the present time, all liquid-metal nuclear submarines are decommissioned [1.33, 1.35, 1.36, 1.37, 1.5].

Power reactor facilities of NS of the third generation were created with consideration for the experience of the second-generation facility operation and taking into account both Three Mile Island (1978) and Chernobyl NPP (1986) accidents [1.38].

The reactor compartment of a nuclear submarine is located within its central part and divides the submarine into a stern group and a nose group of compartments (Figure 1.2.). The main sources of ionizing radiation and radioactive contamination are located within the reactor compartment. The value of ionizing radiation within adjacent compartments is determined by sources presented within the reactor compartment. Their levels depend on the biological protection efficiency.

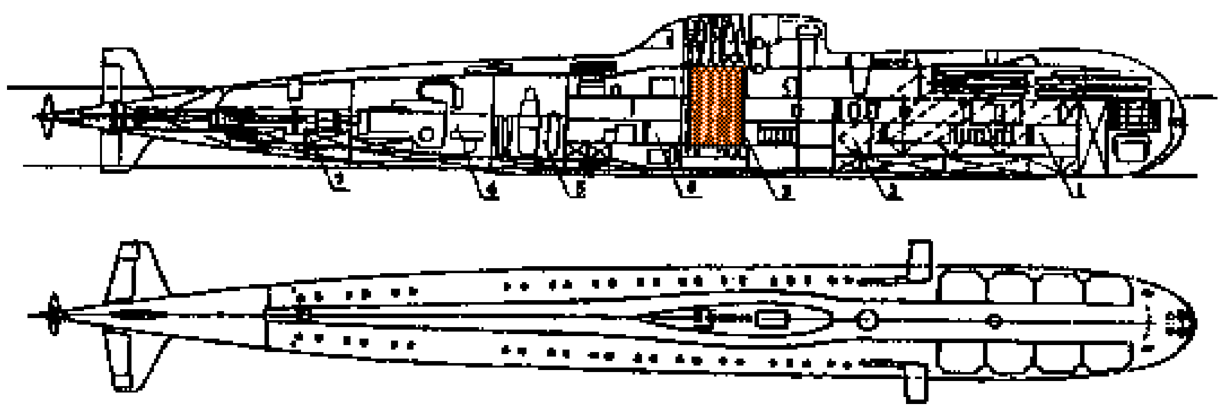


Figure 1.2. General View and Side-view of a Second-generation Nuclear Submarine

1- torpedo compartment, 2 – accumulator compartment, 3 – central post of operative control, 4 – support equipment room, 5 – reactor compartment, 6 – turbine compartment, 7 – compartment of propulsive system and mechanical aid.

As a rule, nuclear submarine berthing spaces are placed in end compartments at a maximum distance from the reactor compartment. Under normal operating conditions, gamma-irradiation exposure dose rate (below dose rate — DR) within habitable nuclear submarine compartments makes up about 10-15 μR/h when the power facility is operating. Due to a special reactor shield providing for biological protection, this value is even lower than that in open air.

It is the steam producing installation (SPI) that represents a radiation-dangerous part of power reactor facility. It consists of the nuclear reactor with control and protection system, coolant circulation circuit (primary circuit), steam generators, secondary circuit and cooling circuit (third circuit). The reactor core, power reactor facility equipment and coolant of the primary circuit are the main sources of radiation danger in nuclear submarines. When operating, the power reactor facility represents a source of gamma-neutron irradiation; when cooled down it is a source of gamma-irradiation [1.74, 1.76, 1.68].

The reactor core contains nuclear fuel based on uranium. The fuel mixture is combined into fuel elements that are united by groups into fuel assemblies (FA). When the reactor is operating, an important amount of fission products are generated in the fuel mixture. Within the technologic mediums and constructional materials of the SPI, many activation radionuclides are created. By the end of the reactor operation time the integral activity of fission radionuclides reaches 10 GCi/370 EBq. To a considerable extent this activity is determined by short-lived radionuclides. Long-lived radionuclides accumulated in the reactor represent potential radioecological hazards (^{90}Sr, ^{137}Cs, ^{60}Co, ^{238,239}Pu, ^{241}Am, et al.).

Protection barriers are created to prevent radionuclide release from areas of their generation, their subsequent accumulation in nuclear submarine compartments, as well as the possibility of their release into the environment. The fuel element (the most dangerous source) has two barriers in the form of fuel mixture matrix and claddings. The fuel mixture is a corrosion-resistant substance able to retain oxide radionuclides due to impregnation with a special solution. The fuel mixture itself decreases fission product release into the coolant in the event of fuel element cladding depressurization. Fuel element claddings are made of corrosion-resistant materials, which prevent radionuclides from being released into the coolant [1.126, 1.1, 1.4, 1.7].

A leak proof primary circuit represents the third barrier, which includes the nuclear reactor vessel, primary circuit structures and pipelines. The vessel, structures and pipelines are made of corrosion-resistant and radiation-resistant materials. They prevent gaseous radioactive fission products from being released. This barrier also includes coolant itself, which slows down neutrons and retains non-gaseous radioactive fission products.

The strong hull of nuclear submarines represents the fourth (and the last) barrier, which prevents radionuclide release into the environment.

1.2.2. Order of NS Utilization

In general, three types of nuclear submarines are to be handled after the decommissioning [1.6, 1.68, 1.77, 1.103, 1.105]:

1. A nuclear submarine is decommissioned from the Navy and is to be dismantled; the reactor core is unloaded, but the equipment of compartments still remains within the nuclear submarine.

2. A nuclear submarine is to be dismantled after long-duration waterborne storage or repair, and cutting out of the missile compartment (shaft). The equipment of other compartments still remains in the submarine. In a case where a nuclear submarine goes to dismantling after long-duration waterborne storage, it can contain a core with fuel; in such a case the core is unloaded prior to the onset of nuclear submarine dismantling.

3. A nuclear submarine is to be dismantled after waterborne storage of long duration, and cutting out of the missile compartment (shaft) and unloading of the reactor core. Within all compartments, part of the equipment is dismantled and unloaded. Another part (that provides for vessel stiffness and floatation when waterborne stored for a long period of time) still remains within the nuclear submarine.

Generally, the process of nuclear submarine dismantling consists of the following four stages:

1. Work under waterborne storage. Are dismantled: deckhouse enclosures, decks and some other elements up to the strong hull without the depressurization of balast tanks; detachable process plates are broken up (and welded at a later time); individual equipment is unloaded on condition that the vessel stiffness is kept.

2. Dry dock or Slip-way work. Are performed:
   - cutting out of reactor compartment (or compartment unit);
   - breaking up of detachable process plates and unloading of the equipment;
   - cutting out of missile compartment unit (unless done before); and
   - sectioning of both the vessel stern and nose into blocks of 100 t at the most and their unloading from the dock (or ship-way).

3. Block cutting into large-volume sections of about 18 ton and their subsequent separation in order to detach the shell from other nuclear vessel elements.

4. Separation of the shell and other nuclear vessel elements to obtain marketable products. This stage is carried out mainly with the use of different machines.

Stages 2 and 3 are performed in dry dock (dock-chamber or floating dock) or within an enclosed working area (slipway).

When dismantling nuclear submarines, the radiation situation is mainly determined by the initial radiation conditions of each individual nuclear submarine. The data characterizing the radiation situation can be subdivided into four basic groups:

- results of calculations;
- results of γ-DR measurements at standard map points on the surface of light hull;
- results of γ-DR measurements and β-contamination of surfaces at standard map points within nuclear submarine compartments; and
- results of γ-DR measurements, β-contamination of surfaces and volumetric activities of aerosols at work places.

1.2.3. Main Radiation Sources within Reactor Compartments [1.2, 1.3, 1.4, 1.8, 1.9]

At the onset of submarine cutting and preparing its radioactive equipment, for long-term storage, there are two types of radiation sources within the reactor compartment as follows:

- volumetric-radiation sources – activated constructional material of power reactor facility elements;
- surface-radiation sources – radionuclide contamination of surfaces of the equipment and nuclear vessel constructions.

The integral activity of these sources, as applied to nuclear vessel power reactor facilities, makes up about 10^4 - 10^5 Ci (0.5 to one year following the shutdown of reactors); note that over 90 percent of long-lived radionuclides are localized within reactor internals.

1.2.4. Characteristics of Radiation Sources Resulting from the Activation of Materials of the Equipment and Structures of Power Reactor Facilities of the Decommissioned Nuclear Submarines

Unfortunately, no representative results of directly measuring the specific activity of materials of power reactor facility equipment and reactor compartment structures are available at the present time. Therefore, only the results of calculated estimates presented in different publications are discussed below. In Table 1.4 approximate values of specific activities of materials (of which are made elements of the power reactor facility equipment and structures of reactor compartments of both the first- and second-generation nuclear submarines equipped with PWR and liquid-metal coolant power facilities) are shown. These results characterize maximal activities corresponding to the material of such parts of the construction that are irradiated, at which maximal (for the volume of specific element) neutron flux densities exerted an impact. The radionuclide composition of induced activity in every individual case is determined by the grade of steel or alloy of which the studied element of equipment/construction is made. That is, induced activity depends on the chemical composition. In the investigation [1.1], radionuclide composition of the activity to be expected in the reactor facility after nuclear fuel unloading is presented.

The results demonstrate that, among radionuclides that create the induced activity of power facility equipment, isotopes emanating X-radiation of 6-7 kev (Fe-55, Ni-63) and β-particles (Ni-63) prevail. Therefore, values of γ-DR close to elements of the activated equipment during the period of 70 to 100 years following the reactor shutdown result from γ-radiation of ^{60}Co. In Table 1.5, values of specific activities of structural steel and γ-DR close to the surface of massive steel structures resulting from the neutron activation process are demonstrated. The results correspond to the activation time t_a=3.5 years and are normalized per unity of thermal neutron flux density.

Table 1.4. Induced Activity of Materials of Nuclear Power Facility Equipment and Reactor Compartment Structures Referred to Nuclear Submarines of the First and the Second Generation Equipped with PWR and Liquid-metal Coolant Reactors, Ci/year [1.2]

Element of equipment or reactor compartment structure	**Specific activity of material after time $t_к$ following reactor shutdown (maximum values)**					
	0.5 year	**2 years**	**5 years**	**10 years**	**50 years**	**100 years**
Shield assembly	$3.0\cdot10^{-2}$ - $9.0.10^{-2}$	$2.0\cdot10^{-2}$ - $6.0\cdot10^{-2}$	$1.3\cdot10^{-2}$- $3.0\cdot10^{-2}$	$4.0\cdot10^{-3}$- $1.0\cdot10^{-2}$	$4.0\cdot10^{-4}$- $1.0\cdot10^{-3}$	$3.0\cdot10^{-4}$- $9.0.10^{-4}$
Reactor vessel	$2.0\cdot10^{-3}$ - $1.0\cdot10^{-2}$	$1.5\cdot10^{-3}$ - $7.0\cdot10^{-3}$	$8.0\cdot10^{-4}$- $3.0\cdot10^{-3}$	$3.0\cdot10^{-4}$- $1.0\cdot10^{-3}$	$5.0\cdot10^{-6}$- $8.0\cdot10^{-6}$	$3.0\cdot10^{-6}$- $6.0\cdot10^{-6}$
Reactor caisson (steel)	$3.0\cdot10^{-3}$ - $6.0\cdot10^{-3}$	$2.0\cdot10^{-3}$ - $4.0\cdot10^{-3}$	$1.0\cdot10^{-3}$- $2.0\cdot10^{-3}$	$4.0\cdot10^{-4}$- $8.0\cdot10^{-4}$	$4.0\cdot10^{-5}$- $1.0\cdot10^{-4}$	$3.0\cdot10^{-5}$- $6.0\cdot10^{-5}$
Reactor caisson (titan alloy)	$2.0\cdot10^{-6}$	$1.3\cdot10^{-6}$	$6.0\cdot10^{-7}$	$2.0\cdot10^{-7}$	$2.0\cdot10^{-8}$	$2.0\cdot10^{-8}$
Lead of protection (in tank)	$4.0\cdot10^{-9}$ $1.0\cdot10^{-8}$	$5.0.10^{-10}$- $1.0\cdot10^{-9}$	$1.6\cdot10^{-10}$- $3.0\cdot10^{-10}$	$2.0\cdot10^{-11}$- $4.0\cdot10^{-11}$	-	-
Steam generator shell (steel)	$2.0\cdot10^{-5}$	$1.0\cdot10^{-5}$	$5.0\cdot10^{-6}$	$1.5\cdot10^{-6}$	$1.0\cdot10^{-8}$	$7.0\cdot10^{-9}$
Steam generator shell (titan alloy)	$1.5\cdot10^{-9}$	$1.0\cdot10^{-9}$	$5.0\cdot10^{-10}$	$1.4\cdot10^{-10}$	$7.0\cdot10^{-13}$	-
Tube bundle of steam generator (titan alloy)	$2.0\cdot10^{-9}$ - $4.0\cdot10^{-8}$	$1.0\cdot10^{-9}$ - $2.0\cdot10^{-8}$	$5.0\cdot10^{-10}$- $1.0\cdot10^{-8}$	$1.5\cdot10^{-10}$- $3.0\cdot10^{-9}$	$7.0\cdot10^{-13}$- $2.0\cdot10^{-10}$	-
Strong hull fragment under the reactor (steel)	$9.0\cdot10^{-4}$	$6.0\cdot10^{-4}$	$3.0\cdot10^{-4}$	$1.0\cdot10^{-4}$	$4.0\cdot10^{-6}$	$3.0\cdot10^{-6}$
Strong hull fragment under the reactor (titan alloy)	$3.0\cdot10^{-7}$	$2.0\cdot10^{-7}$	$1.0\cdot10^{-7}$	$3.0\cdot10^{-8}$	$4.0\cdot10^{-9}$	$4.0\cdot10^{-9}$

The data recalculation makes it possible to observe variations in time of the respective contribution of individual radionuclides into the integral activity (see Table 1.6).

Table 1.5 Specific Activities $a(t_k)$ (Bq/h) and Dose Rates of the Activation Gamma-Irradiation on the Surface of Massive Steel Structures for Different Wait Time $d(t_k)$ (mrem/h) [1.2]

Wait time t_k, years	**Steel grade***					
	OX18H10T		**15X2MΦA**		**AK-29**	
	$a(t_k)$	**$d(t_k)$**	**$a(t_k)$**	**$d(t_k)$**	**$a(t_k)$**	**$d(t_k)$**
0	$5.7\cdot10^{-3}$	$1.6\cdot10^{-5}$	$2.4\cdot10^{-3}$	$5.8\cdot10^{-6}$	$2.4\cdot10^{-3}$	$5.3\cdot10^{-6}$
0.5	$6.6\cdot10^{-4}$	$8.6\cdot10^{-7}$	$7.5\cdot10^{-4}$	$2.4\cdot10^{-7}$	$7.6\cdot10^{-4}$	$3.6\cdot10^{-7}$
2.0	$4.6\cdot10^{-4}$	$7.0\cdot10^{-7}$	$5.1\cdot10^{-4}$	$1.9\cdot10^{-7}$	$5.2\cdot10^{-4}$	$2.9\cdot10^{-7}$
5.0	$2.4\cdot10^{-4}$	$4.7\cdot10^{-7}$	$2.4\cdot10^{-4}$	$1.3\cdot10^{-7}$	$2.5\cdot10^{-4}$	$2.0\cdot10^{-7}$
10.0	$9.1\cdot10^{-5}$	$2.4\cdot10^{-7}$	$7.1\cdot10^{-5}$	$6.5\cdot10^{-8}$	$7.9\cdot10^{-5}$	$1.0\cdot10^{-7}$

Wait time t_k, years	Steel grade*					
	ОХ18Н10Т		15Х2МФА		АК-29	
	$a(t_k)$	$d(t_k)$	$a(t_k)$	$d(t_k)$	$a(t_k)$	$d(t_k)$
20.0	$2.4 \cdot 10^{-5}$	$6.5 \cdot 10^{-8}$	$7.6 \cdot 10^{-6}$	$1.7 \cdot 10^{-8}$	$1.2 \cdot 10^{-5}$	$2.7.10^{-8}$
50.0	$9.7 \cdot 10^{-6}$	$1.3 \cdot 10^{-9}$	$4.0 \cdot 10^{-7}$	$3.4 \cdot 10^{-10}$	$3.1 \cdot 10^{-6}$	$5.3 \cdot 10^{-10}$
100.0	$6.8 \cdot 10^{-6}$	$8.3 \cdot 10^{-12}$	$2.5 \cdot 10^{-7}$	$4.9 \cdot 10^{-13}$	$2.1 \cdot 10^{-6}$	$9.1 \cdot 10^{-13}$
200.0	$3.4 \cdot 10^{-6}$	$4.0 \cdot 10^{-12}$	$1.3 \cdot 10^{-7}$	$2.1 \cdot 10^{-14}$	$1.1 \cdot 10^{-6}$	$11.7 \cdot 10^{-13}$
500.0	$5.3 \cdot 10^{-7}$	$1.2 \cdot 10^{-12}$	$2.0 \cdot 10^{-8}$	$2.0 \cdot 10^{-14}$	$1.8 \cdot 10^{-7}$	$1.7 \cdot 10^{-13}$
1000.0	$1.3 \cdot 10^{-7}$	$5.7 \cdot 10^{-13}$	$4.8 \cdot 10^{-9}$	$2.0 \cdot 10^{-14}$	$4.7 \cdot 10^{-8}$	$1.7 \cdot 10^{-13}$

Comment: * Steel grades are distinguished depending on the concentrations of chromium (the first letter in Russian – (Х), nickel (Н), molybdenum (М) and other elements.

Table 1.6 Relative Contribution of Individual Radionuclides into the Integral Activity of Reactor Unit Equipment of Decommissioned Nuclear Submarine, % [1.2]

Radio-nuclide	Relative contribution into the integral activity for different waiting times (years)					
	0.5	2.0	5.0	10.0	50.0	100.0
^{60}Co	16.81	20.42	26.41	34.26	1.01	$<3.0 \cdot 10^{-3}$
^{63}Ni	3.51	5.12	9.61	23.27	97.56	97.92
^{59}Ni	0.04	0.05	0.09	0.25	1.42	2.08
^{55}Fe	74.70	74.38	63.89	42.12	0.01	$<1.0 \cdot 10^{-4}$
^{58}Co	0.58	$<5.0 \cdot 10^{-3}$	$<1.0E \cdot 10^{-4}$	-	-	-
^{51}Cr	3.97	$<1.0 \cdot 10^{-5}$	-	-	-	-
^{54}Mn	0.08	0.03	$<6.0 \cdot 10^{-3}$	$<1.0 \cdot 10^{-4}$	-	-
^{59}Fe	0.31	$<1.0 \cdot 10^{-5}$	-	-	-	-
^{93}Mo	$1.0 \cdot 10^{-5}$	-	-	-	-	-
^{99}Tc	$<1.0 \cdot 10^{-5}$	-	-	-	-	-

1.2.5 Radioactive Contamination of Surfaces of the Equipment and Vessel Structures

Most measurements of both γ-DR and the contamination density of surfaces of structures and equipment of nuclear submarines to be dismantled after the decommissioning were carried out by reactor unit services of the Navy and ship-repair yards [1.3, 1.4]. The radiation survey demonstrates that under normal operating conditions β-contamination of surfaces in gangways and habitable rooms is unavailable, as a rule. The only exceptions are individual narrow areas (e.g., pipelines and hold): note that in such areas small γ-background is also recorded.

Beta-contamination is mainly concentrated within local areas, the spot surface making up 0.5 to 1.0 m^2. The maximum surface contamination is recorded in equipment baffles (from several hundred up to 5000 - 7000 disintegration/min·cm^2) and on pipelines within the reactor compartment hold (from several hundred up to $2 \cdot 10^5$ disintegration/min·cm^2). The contamination of pipelines is localized due to adsorption processes on insulating materials. In other rooms, β-contamination (disintegration/min·cm^2) is distributed as follows:

- 3rd floor of reactor compartment - from 25 to 120 (700 at the most);
- 2nd floor - from 25 to 600 (800 at the most);
- adjacent compartments - 20-90 (individual points); and
- light hull and strong hull - 20-30 (individual points).

Maximum values of γ-background are observed:

- within equipment baffles (up to 4-5 mR/h);
- on average within the third floors of rector compartments - 0.2 to 0.4 mR/h;
- within the second floors - 0.4 to 2,0 mR/h; and
- in the hold from 0.6 up to 70 mR/h (mainly 30 to 50 mR/h).

Within adjacent compartments, γ-background makes up 0.1 up to 0.2 mR/h.
In most cases, there is a condensate layer 3 to 5 cm thick on the bottom of reactor compartment holds; however, its activity does not exceed the background level ($2 \cdot 10^{-10}$ Ci/L).

Along with the information concerning the radiation situation within a nuclear vessel as well as on the surface of its light hull (stored afloat), the data characterizing the radiation situation of nuclear vessel hulls below the waterline are of major interest.

As shown by measurements performed on slip-way, in the case of the second-generation nuclear submarines, γ-DR under the reactor compartment is considerably higher (up to 150 mR/h) compared to that of the first-generation vessels (18 to 20 mR/h). Therefore, when dismantling such vessels in docks, special protection actions must be undertaken.

The results of radiation monitoring of the biological protection tank (BPT) of the second-generation nuclear submarines (when dried) demonstrate a high degree of the activation of BPT surfaces. These data make it possible to suppose a considerable impact of the state of BPT on the radiation situation within the reactor compartment. This assumption is confirmed by data of Tables 1.7 and 1.8 containing the results of measurements of different parameters of the radiation situation within the reactor compartment and also in adjacent compartments at different states of iron-water protection (IWP) and BPT tanks.

Table 1.7 Radiation Situation within Reactor Compartment of Second-generation Nuclear Submarine (Case of Core Containing Fuel) under Different State of IWP and BPT Tanks [1.9]

Area of measurement	**IWP and BPT tanks are full**		**IWP discharged BPT full**		**IWP discharged BPT full**	
	mR/h	**Disintegration/ cm^2·min**	**mR/h**	**Disinte-gration/ cm^2·min**	**mR/h**	**Disintegra-tion/ cm^2·min**
Equipment baffle	0.72	200-2500	72-108	-	0.72	200-2500
Corridors of the 3rd floor	0.71-7.2	200-10000	0.72-14.4	-	0.72-7.2	200-10000
Pump baffles	0.72-1.44	200-10000	1.44-27	-	0.72-1.44	200-10000
Holds	2.16-3.6	200-12000	54-108	-	2.16-3.6	200-12000
Steam Generator Caissons	36-54	200-2500	720-1800	-	36-54	200-2500
Under biological protection of IWR tank	5.76-108	200-2500	360-3600	-	5.76-108	200-2500
On walls of the 6th and the 8th compartments	0.072-0.144	200-1000	1.44-7.2	-	0.072-0.144	200-1000
Within BPT on strong hull surface	540-2952	8000-15000	1080-3240	-	540-2952	8000-15000
Outside BPT on light hull surface	2.88-108	200-100	7.2-144	-	2.88	200-1000
Close to the primary circuit activity filter	-	-	Up to 3600	-	-	-

Table 1.8 Radiation Situation in Decommissioned Nuclear Submarines (Waiting Time 3 to 5 Years) [1.4]

Area of measurement	**γ-DR, μR/s**		**Contamination density**
	Iron-water protection tank		
	Full	**Discharged**	**Bq/cm^2**
Equipment baffles	0.03 – 5	0.5 – 30	0.8 – 130
Pump baffles	0.02 – 14		3.0 – 200
Through-passage corridors	0.03 – 2	0.2 – 4	0.7 – 200
Holds	0.2 – 40		≤ 350
Walls of compartments adjacent to reactor compartment	0.02 – 0.17	0.4 - 2	≤ 20
Surface of reactor compartment hull: Strong	≤ 250		2 – 250
Light	≤ 20 *		≤ 20

* Biological protection tanks are full

An analysis of this data makes possible the following important conclusions [1.4, 1.8, 1.9]:

- the discharge of IWP tank aggravates the radiation situation by about 100 times on average; the most g-irradiation intensity is recorded in the direction of front walls (an increase by a factor 100 to 10,000) and within the compartment (equipment rooms, pump rooms, holds - by a factor of 100 to 200);
- in BPT outside the strong hull g-background increases twice;
- on the surface of light hull g-background increases by 25-30 percent;
- filling or discharge of IWP tank modifies the radiation situation only slightly (25 to 40 percent) which confirms a high degree of screening by the strong hull;
- when the BPT is filled, the radiation situation becomes normal.

In addition to surface contamination, the reactor compartment equipment is also contaminated on the inside. Specific activity and spectrum composition of radioactive depositions available on inside surfaces of circuit equipment are determined mainly by specific conditions of their creation in the course of nuclear vessel operation.

The contamination of first-generation nuclear submarine equipment is determined by radionuclides of corrosion origin (^{60}Co and ^{54}Mn).

The presence of considerable quantities of fuel mixture fission products ($^{144}Ce+^{144}Pr$, $^{95}Zr+^{95}Nb$, ^{137}Cs, $^{106}Ru+^{106}Rh$ as well as of $^{90}Sr+^{90}Y$) represents a peculiarity of the second-generation nuclear submarines. Note that ^{60}Co fraction determining γ-irradiation hardness (E=1,33 Mev) does not exceed 40 percent of the overall activity of depositions. This phenomenon is explained by the two following reasons:

Under operating conditions and in a case of repair, conservation water regime of the primary circuit considerably mitigates corrosion processes of the constructional materials; and

Operation of practically all primary circuits of the second-generation NS during the second half of operation time was accompanied by different-degree depressurization of the core.

When forming radiation depositions, temperature conditions are also important. All this results in the fact that the deposition thickness within the circuit differs depending on the kind of equipment.

Averaged radionuclide composition of technological depositions created within the primary circuit pipelines, case of the second-generation power facility, can be described as follows (in %):

High-temperature zone:

$^{144}Ce+^{144}Pr$ - 35; ^{60}Co - 30; ^{137}Cs - 20; $^{106}Ru+^{106}Rh$ - 8; ^{54}Mn - 7.

Low-temperature zone:

$^{144}Ce+^{144}Pr$ - 45; ^{60}Co - 30; $^{106}Ru+^{106}Rh$ - 18; ^{54}Mn - 7.

The contamination composition of the remainder primary circuit equipment (%):

$^{144}Ce+^{144}Pr$ - 60; ^{60}Co - 30; ^{54}Mn - 7; ^{137}Cs - 3.

For power facilities of the first generation, the contamination composition of the primary circuit equipment is different (%):

^{60}Co - 85; ^{54}Mn - 10; $^{106}Ru+^{106}Rh$ - 4; $^{144}Ce+^{144}Pr$ - 1.

Thus, in the first-generation power facilities ^{60}Co is the “determining” radionuclide, whereas in those of the second generation ^{137}Cs-radionuclide is most important.

The experience of repair operations regarding power facilities of the second generation demonstrates the following:

- Maximum gamma DRs are recorded on the reactor surface (containing the core) – up to 2 R/h (after cooldown); following the core unloading these values inside an empty caisson make up 35 to 40 R/h at a level of the core arrangement.
- In the case of dismantling the control and protection system equipment on the reactor upper head (assembl. 43,42) without the upper head depressurization, gamma-background within the equipment baffles can be decreased by a factor of 30 to 100 (above the biological protection);
- After bleeding out the contaminated gas of the high-pressure gas (HPG) system (^{85}Kr – $1.3 \cdot 10^{-7}$ Ci/L), the radiation situation becomes normal, as a rule. In cases where in the course of operation a portion of steam/emulsified mixture of gas-coolant is injected into HPG container groups, the radiation situation only can be improved via HPG container dismantling;
- The dismantling of the centrifugal pump of the primary circuit (CPPC), assembl. 60, and the subsequent mounting of protection traps on steam generator hydro-chambers allows reducing DR within the reactor compartment by a factor of 50 to 100 (from 100 mR/h to 1 mR/h) and outside the reactor compartment by 25-40 %;
- Steam generator dismantling makes it possible to improve the radiation situation after biological protection system dismantling by 20 % at the most only;
- The dismantling of activity filters, activity filter cooler and pressurizer allows improving the radiation situation by 5-10 % at the most;
- Reactor dismantling only slightly improves the radiation situation, due to high activities of the reactor compartment constructions; and
- Dismantling and removing reactor compartment equipment located outside the equipment baffle insignificantly modifies the radiation situation outside the nuclear vessel (by 1-2%).

Thus, the following equipment is the most contaminated: reactor caisson, CPPC, and the caisson of the IWP tank. When performing different operations with this equipment as well as when dismantling reactor compartment equipment within damaged nuclear vessels, special protective measures are necessary.

Generalized data [1.3, 1.4, 1.8], which characterize the radioactive contamination of reactor compartment equipment (cases of nuclear submarines of the first and the second generation equipped with PWR and liquid-metal coolant power facilities) are presented in Table 1.9. These data characterize the situation after 6-months wait time following the shutdown.

In the situation of the first-generation submarines with PWR, the contamination of surfaces in most cases results from corrosion products; the main contribution is due to ^{60}Co isotope. In the case of the second-generation submarines the radioactive contamination is formed principally by fission-origin radionuclides: ^{137}Cs, ^{134}Cs, ^{144}Ce, ^{106}Ru, ^{90}Sr. Table 1.10 contains values of respective contribution to the integral activity of the surface contamination of different radionuclides (wait time equals 3 years).

Table 1.9 Radioactive Contamination of Surfaces of Reactor Compartment Equipment and Structures for Decommissioned Nuclear Submarines (wait time up to 6 months) [1.2]

Characteristic of equipment/structure surface	**Specific activity of the contamination, Bq/cm^2**	
	PWR facility	**Liquid-metal coolant power facility**
Inside surfaces of the primary circuit equipment elements	$< 2 \cdot 10^6$	$< 1 \cdot 10^7$
Outside surfaces of equipment within inhabitable rooms of reactor compartment	$2 \cdot 10^4$	$< 2 \cdot 10^6$
Outside surfaces of equipment within habitable rooms of reactor compartment	3.0-200	$1 \cdot 10^3$ - $5 \cdot 10^4$
Outside surfaces of equipment in rooms of non-power compartments	< 20	< 200

Table 1.10 Respective Contribution of Different Radionuclides into the Integral Activity of Surface Contamination of Reactor Compartment Equipment (Case of Nuclear Submarines Equipped with Power Facility of PWR Type), % [1.2]

Radionuclide	**Respective contribution into the integral activity value, %**	
	NS of the first generation	**NS of the second generation**
^{144}Ce - ^{144}Pr	< 1.0	13 – 19
^{137}Cs	< 24	3 – 37
^{106}Ru - ^{106}Rh	5 - 22	
^{90}Sr - ^{90}Y	< 3.0	3 – 6
^{60}Co	70-97	37 – 62
^{54}Mn	3- 5	3 – 10

The data presented in Table 1.9 allow the following conclusion: surface contamination levels of equipment and structures of reactor compartments in a case of nuclear submarines with liquid-metal coolant power facilities are considerably above those of PWR type.

1.2.6. Methods & Results of Estimating the Radiation Potential of Nuclear Submarines (Reactor Units) [1.3, 1.5, 1.8, 1.9, 1.44, 1.63, 1.69, 1.78]

1.2.6.1. Induced Activity in Metal Constructions of Reactor Units

The induced activity of structural and protective materials, and the equipment and coolant impurities of nuclear installations can be determined by radioniclides (products of neutron activation) using the following reactions: (n,γ), (n,p), (n,α), (n,d), (n,2n), (n,n'). Among them the process of thermal and epithermal neutron radiation capture prevails.

The induced activity depends on: flux density and energy spectrum of neutrons, activation cross-section value, chemical element content in materials, relative content of target isotope in chemical element, exposure time and period after shutdown. When dealing with transport reactor units, the following reactions can be considered as basic activation reactions resulting in the generation of long-lived radionuclides with half-life over one year:

$$ {}^{54}_{26}Fe(n,\gamma){}^{55}_{26}Fe \xrightarrow[KX]{2{,}73year} {}^{55}_{25}\underline{Mn} \qquad (5.8\%)$$

$$ {}^{54}_{26}Fe(n,p){}^{54}_{25}Mn \xrightarrow[KX,\gamma]{312{,}12d} {}^{54}_{24}\underline{Cr} \qquad (5.8\%)$$

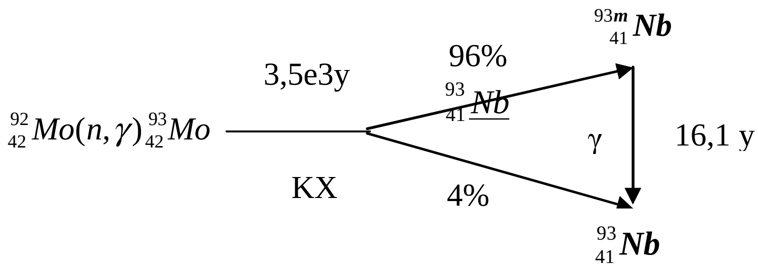
$$ {}^{59}_{27}Co(n,\gamma){}^{60}_{27}Co \xrightarrow[\beta^-,\gamma]{5{,}2709y} {}^{60}_{28}\underline{Ni} \qquad (100\%)$$

$$ {}^{58}_{28}Ni(n,\gamma){}^{59}_{28}Ni \xrightarrow[KX]{2{,}9e5y} {}^{59}_{27}\underline{Co} \qquad (67.8\%)$$

$$ {}^{60}_{28}Ni(n,p){}^{60}_{27}Co \xrightarrow[\beta^-,\gamma]{5{,}2709y} {}^{60}_{28}\underline{Ni} \qquad (26.4\%)$$

$$ {}^{63}_{29}Cu(n,\alpha){}^{60}_{27}Co \xrightarrow[\beta^-,\gamma]{5{,}2709y} {}^{60}_{28}\underline{Ni} \qquad (69.1\%)$$

$$ {}^{63}_{29}Cu(n,p){}^{63}_{28}Ni \xrightarrow[\beta^-]{101{,}1y} {}^{63}_{29}\underline{Cu} \qquad (69.1\%) $$



(14.8%)

The content of target isotope in natural mixture is given in parentheses.

To calculate the induced activity it is wise to introduce a notion of activation integral, which characterizes the reaction rate. The activation integral q referred to one nucleus of target isotope equals:

$$ q = \int_0^\infty \sigma(E)\varphi(E)dE \qquad (1) $$

where: σ(E) = cross-section of the activation reaction for E energy, φ(E) = energy spectrum of neutrons.

When solving most practical issues, secondary processes (such as, e.g., target isotope burnup of the reaction product) can be neglected. In this case, the induced volumetric activity A_V of reaction product isotope with a disintegration constant λ in material possessing target isotope atom number in a unit of volume n_0 for exposure time T within a stable neutron flux after a time t following the exposure termination makes up:

$$ A_V = n_0 q(1 - e^{-\lambda T})e^{-\lambda t} \qquad (2) $$

For an unstable in time neutron flux, a number l of time intervals can be distinguished; as a result, during j-interval flux density T_j is to be considered as a stable value. In this case, the integral induced activity is determined by superposition of induced activities of every j-interval. Thus:

$$A_V = n_0 \sum_{j=1}^{l} q_j (1 - e^{-\lambda T_j}) e^{-\lambda t_j} \qquad (3)$$

where: t_j = time after the termination of j-interval of exposure.

In the work [1.1], the results of calculating the induced activity of reactor compartment construction and protection materials (two identical reactor units) are presented for averaged modes of operation of the first-generation nuclear submarines.

In Table 1.11 the results of calculating the integral induced activity of reactor compartment constructions are given. The largest contribution to the induced activity value is due to reactor internals (as a result of a high content of nickel addition in X18H10T stainless steel used in reactor internals, as compared to high-carbon steel of the reactor vessel). Activities of other reactor compartment elements (reactor vessel constructions, iron-water protection tank, basements and strong nuclear submarine vessel under the reactor compartments, as well as steam generator baffle structures) are by more than an order of magnitude less.

Starting from the results of [1.1] and knowing the power history, one can estimate «activation integrals» Q' = n_0qV (where n_0 = target isotope nucleus number in a unit of volume, V = reactor compartment volume) for 21 Mw power with consideration for radionuclides given in Table 1.11. Here, an equilibrium activity (over infinite exposure time) of the overall reactor compartment is understood under the activation integral. Q value makes no physical sense since the effects of target isotopes of the activation product burn up over an infinite period of time (neglected in equation (2)) become considerable. However, this value makes it possible to estimate satisfactorily the reactor compartment activity, as applied to the real history of the considered nuclear submarine reactor operation at full power (see below).

Table 1.11. Integral Induced Activity of Constructions in Nuclear Submarine Reactor Compartment, Bq

Nuclide	**Time following the reactor shutdown, years**							
	0.5	**5**	**10**	**30**	**70**	**100**	**500**	**1000**

Nuclide	Time following the reactor shutdown, years							
	0.5	**5**	**10**	**30**	**70**	**100**	**500**	**1000**
^{54}Mn	2.48E+14*	6.49E +12	1.13E +11	1.04E +4	-	-	-	-
^{55}Fe	7.1E +15	2.26E +15	6.32E +14	3.85E +12	1.44E +8	6.89E +4	-	-
^{60}Co	1.63E +15	1.02E +15	5.2E 7+14	3.79E +13	1.97E +11	3.78E +9	-	-
^{59}Ni	4.25E +12	4.25E +12	4.25E +12	4.25E +12	4.25E +12	4.25E +12	4.23E +12	4.21E +12
^{63}Ni	3.61E +14	3.48E +14	3.38E +14	2.93E +14	2.23E +14	1.8E +14	1.14E +13	3.54E +11
^{93}Mo	2.5E +9	2.5E +9	2.5E +9	2.5E +9	2.46E +9	2.46E +9	2.26E +9	2.05E +9
Total	9.89E +15	3.64E +15	1.5E +15	3.41E +14	2.27E +14	1.86E +14	1.57E +13	4.6E +12

*) Here and later the record of “2,48E+14”-type is to be understood as “$2{,}48\cdot10^{14}$”

Values of Q’ (recalculated with reference to one reactor) for radionuclides listed in Table 1.11 are demonstrated in Table 1.12.

Table 1.12 Reactor Compartment Activity for a Power of 21 Mw over infinite exposure time (the last line contains Q’ activation integral values per unit power)

Nuclide	^{60}**Co**	^{55}**Fe**	^{59}**Ni**	^{63}**Ni**	^{54}**Mn**	^{93}**Mo**
Q’, Bq	4.7E+15	2.0E +16	5.0E +16	6.0E +15	1.0E +14	1.4E +12
Q, [Bq/Mw]	2.2E +14	9.5E +14	2.4E +15	2.9E +14	4.8E +12	6.7E +10

Given nuclear submarine operating time as average annual indices during N years – average energy-production during i-year W_i [Mw·h] and time of full power operation T_i [h], the activity of reactor compartment A for a radionuclide with λ disintegration constant for a given time t can be estimated as follows:

$$A(t) = Q\sum_{i=1}^{N}\frac{W_i}{T_i}(1-e^{-\lambda T_i})e^{-\lambda t_i} \qquad (4)$$

where: t_i = period of time from the end of i-year of reactor operation to the given time, t.

The equation (4) contains a number of assumptions. In particular:

- each radionuclide production during the operating period is assumed linearly proportional to power value;

- as fuel burns up, changes in neutron energy spectrum are not taken into account;
- power history during one year is neglected;
- element composition of steel is considered as constant for the whole compartment.

However, for long-lived radionuclides (their production during the operation period varies in direct proportion to energy-production), real consideration of the above-listed factors will result in a correction of 10-20% at the most. Thus, the precision of induced activity estimates within the reactor compartment using the equation (4) can be considered as 20% worse than that of calculations performed in the Report [1.1].

To estimate the calculation accuracy [1.1], special experimental investigations of induced activity were performed. For these purposes, samples of materials cut out of the vessel of 27 BM bench installation (a surface prototype of the first-generation nuclear submarines, Obninsk town) were used. The bench installation was put into operation in 1956 and its energy-production over 30 years made up 1898000 Mw·h [1.1]. Samples of heat shield inside the reactor, the vessel interior lining and the vessel itself were studied. For samples of heat shield and the reactor interior lining (made of X18H10T steel of maximum specific activity), the calculated specific activity value of samples for ^{60}Co and ^{63}Ni is about two times higher. The authors explain the discrepancy between experimental and calculated results by distinctions between the real element composition of steel from that used in the calculations. The authors do not mention whether or not they took into account the history of the unit operation at full power.

There is almost no way of taking into account real geometry of constructions (the authors [1.1] give steel specific activity calculations only with reference to two directions – «upward» and «stern» with maximum specific activity differing by about three times). Therefore, the calculated estimations of induced activity within the reactor compartment can be treated as true ones with an accuracy of no less than an order of magnitude.

Note that to estimate the radiation potential of the reactor compartment as a whole, consideration of only the induced activity of reactor internals is sufficient within the accuracy of calculations. According to estimations [1.1]:

- the activity of reactor vessel constructions makes up about 4%,
- that of iron-water protection tank structures is equal to 1%, and
- the activity of strong vessel basement under the reactor baffles and that of constructions within steam generator baffles makes up <0.001% from the induced activity inside the reactor vessel.

1.2.6.2. Estimates of Surface Deposition Radioactivity on Metallic Constructions Inside the Reactor and the Primary Circuit

Along with radioactive isotopes of the activation origin distributed over the metal volume, some radionuclides are also presented on metallic construction surfaces inside the reactor and the primary circuit, as a part of corrosion depositions. These are the same isotopes of iron, cobalt, nickel, etc., but also products of ^{235}U fission, which reach the coolant via depressurized claddings (especially ^{90}Sr and ^{137}Cs). Though the activity of corrosion depositions is about 3 orders of magnitude less than the induced activity, radionuclides found on the construction surfaces reach the environment more easily since they are not bound in metals. Therefore, in the event of primary circuit depressurization they present a serious hazard.

The most hazardous isotopes and their maximum expected activities in surface depositions at the instant of reactor shutdown are presented in Table 1.13. Initial data of Report [1.1] were used in calculations.

Table 1.13. Nuclide Activities on Inside Surfaces of Pipelines of the Primary Circuit $A_{S,i}$, Bq.

Isotope	$A_{S,i}$
^{55}Fe	4.3E +11
^{60}Co	5.9E +11
^{59}Ni	5.5E +8
^{63}Ni	8.2E +10
^{90}Sr	6.4E +10
^{137}Cs	2.1E +11
^{54}Mn	2.3E +12

The mechanism of generation and transfer of active corrosion products within circuits is rather sophisticated. It represents the function of a number of parameters, i.e.: temperature, pressure, pH value, oxygen availability in water of the circuit, coolant circulation rate, circuit surface material, corrosion rate, availability of a directed heat flux, coolant flow rate for cleaning, filter efficiency, reactor power level, degree of fuel element cladding depressurization, and so on. It seems that there is no way of exactly calculating the accumulation of corrosion products. Table 1.13 demonstrates maximum expected activities of corrosion deposits obtained as a result of the following (very conservative) assumptions: - the reactor unit operates at a power of about 20 Mw during 40-50 thousand hours and - fuel element claddings are depressurized in large measure. Minimum values are less by two orders of magnitude.

Thus, one can suppose that the calculation of corrosion product activities using the data of Table 1.13 gives an upper estimate with a reserve of about an order of magnitude. It seems that at the present time there is no way of calculating surface deposition activities in circuits more accurately. To obtain more exact estimations the use of experimental results for every nuclear submarine is necessary.

1.2.6.3. Estimates of Fission-Fragment Activity in Fuel of Nuclear Submarine Reactor

When performing evaluation calculations (in which linear dependence of fission isotopes from energy production of the core is supposed from the instant of reactor shutdown), one can use the data of report [1.2]. The work concentrates on the results of calculating the fission-fragment activity of - “Lenin” icebreaker sunken reactor compartment, - six nuclear submarine reactors and - a power reactor facility of “Sevmorput” lighter-aboard ship. In these calculations, the real history of reactor operation at full power was taken into account. Averaged evaluations of long-lived fission product activities normalized to unity of energy production are demonstrated in Table 1.14.

One can see that the hypothesis of linear dependence of accumulating activities due to energy production with regard to the real reactor operating period gives a satisfactory result for most radionuclides (the accuracy of about 30 to 50%). The exceptions are radionuclides of ^{134}Cs-type, since their activity depends nonlinearly on burnup. Considering that operating periods and energy production of most nuclear submarine reactors differ only slightly from those used in [1.2], the accuracy of initial data presented in Table 1.14 is no less than a factor of two.

Table 1.14 Average Values of Normalized Activities of Long-lived Fission Products and their Standard Deviations by the Instant of Reactor Shutdown

Nuclide	$T_{1/2}$	**Activity, Bq/(Gw*day)**
^{3}H	12.3 years	(7.5±1.6)E +11
^{85}Kr	10.7 years	(1.8±0.6)E +13
^{90}Sr	29.1 years	(1.1±0.1)E +14
^{99}Tc	2.13+5 years	(1.70±0.04)E +10
^{129}I	1.57+7 years	(2.8±0.1)E +7
^{134}Cs	2.06 years	(2.7±2.3)E +13
^{135}Cs	2.3+6 years	(8.5±2.1)E +8
^{137}Cs	30.0 years	(1.2±0.1)E +14
^{147}Pm	2.62 years	(3.6±1.0)E +14
^{151}Sm	90 years	(2.6±1.1)E +12
^{152}Eu	13.3 years	(2.3±1.7)E +10
^{154}Eu	8.8 years	(4.4±2.5)E +11
^{155}Eu	4.96 years	(3.0±1.5)E +12

In is worth noting that such a simplified approach cannot be used to estimate transuranium element (TUE) activity accumulations. The accumulation of TUE activities depends strongly on neutron spectrum and power density and varies substantially in non-linear fashion with fuel burnup. Simplified approaches, such as that used to estimate fission radionuclide accumulation (see Table 1.14) can lead to errors of up to two orders of magnitude and are inapplicable in principle. To obtain adequate valuations, real dependencies of TUE accumulation should be used. However, in our opinion exact values of accumulated TUE activities are of little importance at the current stage of the investigations; therefore, such calculations are omitted.

1.2.6.4. Peculiarities of Calculating the Radiation Potential of NS of the Second Generation

To estimate the induced activity within metallic constructions of the reactor compartment, initial data of the report [1.4] were used. Similar to nuclear submarines of the first generation, in this case over 95 percent of induced activity is also concentrated within reactor internals. The results presented in a report [1.4] related to the accumulation of basic radionuclides within reactor internals of the second-generation nuclear submarines at the instant of reactor shutdown are demonstrated in Table 1.15.

Table 1.15. Activities of Basic Radionuclides within Reactor Internals of the Second-Generation Nuclear Submarines by the Instant of Reactor Shutdown

Radionuclide	**^{60}Co**	**^{54}Mn**	**^{55}Fe**	**^{59}Ni**	**^{63}Ni**
Activity, Bq	4.8E +14	3.4E +14	9.3E +15	6.3E +11	7.4E +13

In the calculations, nonstop operation of two 90 Mw BM-4-type reactors during 60,000 hours at a power level of 20 percent from the rated value was supposed.

The results of Q activation integral calculations using the equation (4) are demonstrated in Table 1.16.

It is worthy of notice that in the case of nuclear submarines of the second generation the activation integrals make up 0.02…0.03 from those of NS of the first generation. This difference is due to their construction distinctions (BM-A and BM-4): within reactor internals of the second-generation nuclear submarines, amounts of 1X18H10T stainless steel are considerably less.

Table 1.16. Activation Integrals per Unit Power for Induced Activity (Case of Reactor Internals of the Second-generation Nuclear Submarines)

Nuclide	**^{60}Co**	**^{55}Fe**	**^{59}Ni**	**^{63}Ni**	**^{54}Mn**	**^{93}Mo***
Q, Bq/Mw	9.2+12	1.3+14	1.1+14	1.7+13	4.3+12	3.2+9

**The work [1.4] does not contain calculations for 93Mo. The value of induced activity for nuclear submarines of both the first and the second generations is determined mainly by the same 1X18H10T steel. Therefore to estimate 93Mo activity the mean relation of activation integrals of ^{60}Co u ^{59}Ni for nuclear submarines of the first and the second generation was used.*

To perform practical calculations of sufficient accuracy, the activity of surface depositions and the fission-fragment activity in fuel of the second-generation nuclear submarines can be estimated using the same formulas as for the first-generation nuclear submarines.

Similar to previous calculations, the estimated accuracy of the results obtained constitutes an order of magnitude.

1.2.6.5 Radiation Potential of the First-Generation Nuclear Submarines (as of January 01, 2002)

Table 1.17

№	**Serial number**	**NATO Classification**	**Radiation potential, 2002, Bq**			**Radiation potential, 2012, Bq**		
			Core	**Reactor compart-ment**	**Σ**	**Core**	**Reactor compart-ment**	**Σ**
1	283	November		3.51E+14	3.51E+14		2.20E+14	2.20E+14
2	287	November		2.20E+14	2.20E+14		1.45E+14	1.45E+14
3	254	November	6.28E+14	1.62E+14	7.90E+14	1.05E+14	4.80E+14	5.85E+14
4	289	November	4.18E+15	3.65E+14	4.54E+15	3.11E+15	1.91E+14	3.30E+15
5	260	November		3.47E+14	3.47E+14		1.83E+14	1.83E+14
6	284	November	3.25E+15	3.77E+14	3.63E+15	2.39E+15	1.96E+14	2.59E+15
7	285	November		4.05E+14	4.05E+14		2.07E+14	2.07E+14
8	291	November	3.10E+15	3.41E+14	3.45E+15	2.28E+15	1.80E+14	2.46E+15
9	904	Hotel		2.32E+14	2.32E+14		1.69E+14	1.69E+14
10	902	Hotel	9.17E+14	2.12E+14	1.13E+15	6.96E+14	1.40E+14	8.36E+14
11	905	Hotel		3.12E+14	3.12E+14		1.96E+14	1.96E+14
12	901	Hotel	1.60E+15	1.92E+14	1.79E+15	1.23E+15	1.35E+14	1.36E+15
13	907	Hotel	6.79E+14	2.98E+14	9.77E+14	4.99E+14	1.66E+14	6.65E+14
14	540	Echo-II		4.81E+14	4.81E+14		2.47E+14	2.47E+14
15	545	Echo-II		4.54E+14	4.54E+14		2.50E+14	2.50E+14
16	530	Echo-II		3.23E+14	3.23E+14		1.62E+14	1.62E+14
17	531	Echo-II	4.06E+15	5.70E+14	4.63E+15	2.99E+15	2.50E+14	3.24E+15
18	533	Echo-II		6.70E+14	6.70E+14		2.98E+14	2.98E+14

№	Serial number	NATO Classification	Radiation potential, 2002, Bq			Radiation potential, 2012, Bq		
			Core	Reactor compart-ment	Σ	Core	Reactor compart-ment	Σ
19	536	Echo-II		3.71E+14	3.71E+14		1.90E+14	1.90E+14
20	543	Echo-II	1.32E+15	2.61E+14	1.58E+15	1.01E+15	1.59E+14	1.17E+15
21	532	Echo-II	4.11E+15	5.62E+14	4.67E+15	2.97E+15	2.35E+14	3.21E+15
22	542	Echo-II	2.08E+15	6.90E+14	2.77E+15	1.50E+15	3.21E+14	1.82E+15
23	535	Echo-II	3.19E+15	7.75E+14	3.96E+15	2.26E+15	3.56E+14	2.62E+15
24	537	Echo-II	1.63E+15	6.35E+14	2.26E+15	1.18E+15	2.93E+14	1.47E+15
25	539	Echo-II	3.37E+15	5.67E+14	3.94E+15	2.33E+15	2.32E+14	2.57E+15
26	534	Echo-II		5.57E+14	5.57E+14		2.44E+14	2.44E+14
27	538	Echo-II		6.23E+14	6.23E+14		2.71E+14	2.71E+14
28	544	Echo-II		7.13E+14	7.30E+15		3.10E+14	3.16E+14
29	906	Hotel		2.61E+14	2.61E+14		1.32E+14	1.32E+14

1.2.6.6. Radiation Potential of the Second-Generation Nuclear Submarines (as of January 01, 2002)

Table 1.18

№	Serial number	NATO Classification	Radiation potential, 2002, Bq			Radiation potential, 2012, Bq		
			Core	Reactor compart-ment	Σ	Core	Reactor compart-ment	Σ
1	902	Charley-II		2.41E+13	2.41E+13		8.50E+12	8.50E+12
2	903	Charley-II		4.78E+13	4.78E+13		1.41E+13	1.41E+13
3	904	Charley-II		4.70E+13	4.70E+13		1.21E+13	1.21E+13
4	905	Charley-II		5.76E+13	5.76E+13		1.28E+13	1.28E+13
5	911	Charley-II		4.80E+13	4.80E+13		1.17E+13	1.17E+13
6	901	Charley-II		4.63E+13	4.63E+13		1.19E+13	1.19E+13
7	600	Victor-I	6.38E+15	5.25E+13	6.43E+15	4.62E+15	1.78E+13	4.63E+15
8	601	Victor-I	5.05E+15	3.76E+13	5.09E+15	3.58E+15	1.47E+13	3.60E+15
9	604	Victor-I	4.95E+15	6.04E+13	5.01E+15	3.58E+15	1.94E+13	3.60E+15
10	615	Victor-I		4.51E+13	4.51E+13		1.55E+13	1.55E+13
11	603	Victor-I	6.02E+15	8.55E+13	6.10E+15	4.17E+15	2.25E+13	4.19E+15
12	605	Victor-I	7.82E+15	1.11E+14	7.93E+15	5.41E+15	2.67E+13	5.44E+15

№	Serial number	NATO Classification	Radiation potential, 2002, Bq			Radiation potential, 2012, Bq		
			Core	Reactor compart-ment	Σ	Core	Reactor compart-ment	Σ
13	606	Victor-I	5.57E+15	8.37E+13	5.65E+15	3.85E+15	2.21E+13	3.88E+15
14	613	Victor-I	2.70E+15	3.39E+13	2.74E+15	2.07E+15	1.46E+13	2.08E+15
15	621	Victor-II	3.48E+15	6.52E+13	3.54E+15	2.52E+15	1.84E+13	2.53E+15
16	625	Victor-II	2.60E+15	5.22E+13	2.65E+15	1.80E+15	1.57E+13	1.81E+15
17	804	Victor-II		2.98E+13	2.98E+13		1.10E+13	1.10E+13
18	627	Victor-II	2.15E+15	9.07E+13	2.24E+15	1.49E+15	2.13E+13	1.51E+15
19	609	Victor-I	6.18E+15	6.28E+13	6.24E+15	4.15E+15	1.80E+13	4.17E+15
20	608	Victor-I	6.55E+15	9.44E+13	6.65E+15	4.25E+15	2.13E+13	4.27E+15
21	611	Victor-I	9.38E+15	1.41E+14	9.52E+15	6.07E+15	3.06E+13	6.11E+15
22	801	Victor -II	3.20E+15	7.44E+13	3.28E+15	2.15E+15	1.64E+13	2.17E+15
23	802	Victor -II		2.80E+13	2.80E+13		1.14E+13	1.14E+13
24	602	Victor -I	7.79E+15	7.67E+13	7.86E+15	4.83E+15	2.02E+13	4.85E+15
25	803	Victor -II		6.52E+13	6.52E+13		1.88E+13	1.88E+13
26	501	Papa	3.22E+15	1.90E+13	3.24E+15	2.47E+15	7.46E+12	2.48E+15
27	512Э	Juliett	4.01E+13	3.92E+11	4.05E+13	2.95E+13	9.80E+10	2.96E+13
28	638	Victor -III	3.65E+15	3.37E+13	3.68E+15	2.59E+15	8.16E+12	2.60E+15
29	301	Victor -III		5.92E+13	5.92E+13		1.52E+13	1.52E+13
30	645	Victor -III	9.89E+14	5.74E+13	1.05E+15	6.41E+14	1.35E+13	6.55E+14
31	647	Victor -III	7.62E+15	1.03E+14	7.72E+15	5.27E+15	1.99E+13	5.29E+15
32	652	Victor -III	6.71E+15	1.62E+14	6.87E+15	4.51E+15	2.82E+13	4.54E+15
33	296	Victor -III	1.01E+16	1.71E+14	1.03E+16	5.96E+15	2.57E+13	5.99E+15
34	297	Victor -III	9.77E+15	1.24E+14	9.89E+15	5.75E+15	2.10E+13	5.77E+15
35	649	Victor -III	7.36E+15	1.05E+14	7.46E+15	4.33E+15	1.72E+13	4.35E+15
36	641	Victor -III	7.88E+15	1.16E+14	8.00E+15	4.53E+15	1.81E+13	4.57E+15
37	636	Victor -III	8.12E+15	1.21E+14	8.24E+15	4.71E+15	1.96E+13	4.73E+15
38	643	Victor -III	9.24E+15	1.11E+14	9.35E+15	5.43E+15	1.78E+13	5.45E+15
39	424	Yankee		3.6E+13	3.6E+13		1.8E+13	1.8E+13
40	422	Yankee		1.89E+13	1.89E+13		1.22E+13	1.22E+13
42	402	Yankee		3.2E+13	3.2E+13		1.6E+13	1.6E+13
43	401	Yankee		3.76E+13	3.76E+13		1.83E+13	1.83E+13
44	400	Yankee		1.71E+13	1.71E+13		1.07E+13	1.07E+13
45	431	Yankee		5.16E+13	5.16E+13		2.10E+13	2.10E+13

№	Serial number	NATO Classification	Radiation potential, 2002, Bq			Radiation potential, 2012, Bq		
			Core	Reactor compart-ment	Σ	Core	Reactor compart-ment	Σ
46	423	Yankee		4.63E+13	4.63E+13		2.04E+13	2.04E+13
47	441	Yankee		7.10E+13	7.15E+13		2.45E+13	2.45E+13
48	421	Yankee		5.60E+13	5.60E+13		1.89E+13	1.89E+13
49	452	Yankee		5.48E+13	5.48E+13		2.16E+13	2.16E+13
50	462	Yankee		9.68E+13	9.68E+13		2.90E+13	2.90E+13
51	451	Yankee		1.10E+14	1.10E+14		3.07E+13	3.07E+13
52	470	Yankee		9.69E+13	9.69E+13		2.62E+13	2.62E+13
53	414	Yankee	5.18E+15	2.70E+13	5.21E+15	3.68E+15	1.60E+13	3.69E+15
54	461	Yankee		9.48E+13	9.48E+13		2.53E+13	2.53E+13
55	420	Yankee	1.82E+15	1.07E+14	1.93E+15	1.26E+15	2.84E+13	1.29E+15
56	432	Yankee	3.71E+15	2.79E+13	3.74E+15	2.49E+15	1.29E+13	2.51E+15
57	440	Yankee	3.74E+15	5.57E+13	3.79E+15	2.51E+15	1.73E+13	2.53E+15
58	310	Delta-I		4.71E+13	4.71E+13		1.91E+13	1.91E+13
59	312	Delta-I		9.81E+13	9.81E+13		7.07E+13	7.07E+13
60	326	Delta-I		1.46E+14	1.46E+14		7.07E+13	7.07E+13
61	337	Delta-I		1.06E+14	1.06E+14		7.07E+13	7.07E+13
62	339	Delta-I		1.95E+14	1.95E+14		7.07E+13	7.07E+13
63	338	Delta-I		1.41E+14	1.41E+14		7.07E+13	7.07E+13
64	324	Delta-I		9.72E+13	9.72E+13		7.07E+13	7.07E+13
65	325	Delta-I		8.14E+13	8.14E+13		6.89E+13	6.89E+13
66	341	Delta-II		1.67E+14	1.67E+14		3.36E+13	3.36E+13
67	354	Delta-II		1.67E+14	1.67E+14		3.36E+13	3.36E+13
68	353	Delta-II		1.48E+14	1.48E+14		3.31E+13	3.31E+13
69	342	Delta-II		1.26E+14	1.26E+14		2.76E+13	2.76E+13
70	355	Delta-III		1.69E+14	1.69E+14		3.36E+13	3.36E+13
71	373	Delta-III		2.55E+14	2.55E+14		4.25E+13	4.25E+13

1.2.6.7. Radiation Potential of the Third-Generation Nuclear Submarines (as of January 01, 2002)

Table 1.19

№	Serial number	NATO Classification	Radiation potential, 2002, Bq			Radiation potential, 2012, Bq		
			Core	Reactor compart-ment	Σ	Core	Reactor compart-ment	Σ
1	712	Typhoon	1.76E+16	2.14E+14	1.78E+16	1.19E+16	4.24E+13	1.19E+16
2	713	Typhoon	2.03E+16	3.25E+14	2.07E+16	1.32E+16	5.46E+13	1.32E+16
3	724	Typhoon	2.68E+16	4.48E+14	2.73E+16	1.58E+16	6.94E+13	1.59E+16
4	3001	Shark	8.27E+15	1.15E+14	8.39E+15	5.56E+15	2.13E+13	5.58E+15
5	605	Oscar		1.10E+14	1.10E+14		3.00E+13	3.00E+13
6	606	Oscar	1.31E+16	1.41E+14	1.33E+16	9.31E+15	3.16E+13	9.35E+15
7	617	Oscar	1.18E+16	1.91E+14	1.19E+16	6.92E+15	3.00E+13	3.00E+13
8	662	Oscar	1.31E+16	1.14E+14	1.32E+16	9.31E+15	2.98E+13	9.34E+15

1.3. Spent Nuclear Fuel (SF) Management in the North-West Region

1.3.1. Amount, Radiation Potential, and SF Storage Sites in the Murmansk Region [1.32, 1.33, 1.34, 1.35, 1.63, 1.66, 1.69, 1.70, 1.78, 1.79, 1.85, 1.89, 1.90]

In the Murmansk region, SF is stored at the coastal servicing enterprises (CSE) in Andreeva Bay, in Gremikha settlement, at the «Atomflot» enterprise (Murmansk city), and at the floating servicing enterprises (FSE) and in nuclear submarines pending for defueling (see Table 1.20).

Table 1.20 Amount and Storage Places of SF in the Northwest region

No	SF storage places	Number of the SFA	Total activity, Ci
Arkhangelsk region			
1.	Severodvinsk	958	$5{\cdot}10^6$
Murmansk region			
2.	Snezhnogorsk	1106	$5.8{\cdot}10^6$
3.	Gremikha	778	$4.1{\cdot}10^6$
4.	Zaozersk	21631661	$114.1{\cdot}10^6$
5.	Murmansk	661	$3.5{\cdot}10^6$
	Total:	25134	$132.5{\cdot}10^6$
6.	In 44 NS of the Murmansk region		$92{\cdot}10^6$
7.	In 6 NS of the Arkhangelsk region		$20{\cdot}10^6$
	Total:		$112{\cdot}10^6$
	Integral amount:		$244.5{\cdot}10^6$

1.3.1.1. CSE in Andreeva Bay

The base is located on the Kola Peninsula in the Motovsky Gulf of the Barents Sea, on the western coast of the bay Zapadnaya Litsa. The territory area is 0.23 km^2.

The SFA storage (building 5) was commissioned in two stages: the first stage in 1962, the second stage in 1973. The storage design includes rectangular reinforced-concrete pools of 1000-m^3 total volume covered from inside by carbon steel 3 mm thick with polymer facing and common transportation passage. The design capacity of the storage is 2000 packages (14000 SFA). During the active use period, the capacity of CSE storage in Andreeva Bay was increased to 2550 packages (550 packages in the first-stage storage and 2000 packages in the second-stage storage).

In November 1982, the water level in the left pool fell down, and the use of the pool was stopped. In the first stage of addressing the accident consequences, 900 SFA packages were placed in the idle deepened coastal tanks for LRW storing reconstructed for the “dry” storing of the SFA. In 1983–1984, part of these SFAs were transported to the PA “Mayak” for reprocessing. In 1989, the second stage of storage unloading (right pool) was performed: all SFA in the building (approximately 1400 packages, including 70 packages remaining in the left pool) were unloaded. At the moment, the building is not used as storage of SFA; its technical state is unsatisfactory. All SFA are unloaded from the building and the water is removed. However, there is some residue of the fallen SFA on the pool bottom. The total activity of the radionuclides in the residue is ~4 Ci / ~0.15 PBq; the radionuclide content is unknown.

The block of “dry” storage of SFA was build to store SF unloaded from building 5 and coming from planned refueling (defueling) of reactor cores. The block is designed in the form of three deepened reinforced-concrete tanks, each 1000 m^3 in volume, covered by carbon steel. The capacity of the dry storage block is:

- building 3A - 1200 cells for SFA packages;
- building 2A - 1220 cells for SFA packages;
- building 2B - 1191 cells for SFA packages and 30 cells for control rods.

As of the end of 2001, the cells are virtually completely filled by the SFA.

Fig. 1.3. Former SFA storage (building 5) at the CSE in Andreeva Bay

1.3.1.2. CSE in the Gremikha Settlement

The base is located at Yokan'gskii Gulf of the Barents Sea, in Cherviachnaia Bay and occupies 0.15 km^2.

The storage of the SFA from PWR (building 1) includes four pools, each 70 m^3 in volume, and a common technological hall. The total capacity of the storage is approximately 1500 SFA. The SFA are stored under a water layer (for cooling and protection). Upon leakage in 1984, all four pools were dried, the stored SFA were unloaded and carried away except 95 SFAs that were broken and unacceptable for transportation to the reprocessing facility. They were placed in the fourth pool. At the moment, all SFA from all pools are unloaded, and virtually all water from the pools is removed. Small amounts of water with radioactive mud-like sediment are present at the bottom of the pools. The measurements performed upon unloading of the SFA showed that the DR-value in the technological hall varies from 7 to 10 μR/h. However, there are some locations where DR reaches 100-200 mR/h. The surface contamination picture is similar, i.e., the average contamination is 1500 β-particles /cm^2·min; the maximum is 125000 β-particles /cm^2·min. The radiation situation in the working apartments is generally normal. The DR in the storage pools is 100 mR/h, the maximum value is 1.6 R/h.

Storage of spent extractable parts (SEP) of the NS fuel assemblies with LMC (building 1B) is aimed at the long-term storage of the SEP with natural cooling. The storage capacity is eight SEP. At the moment, six SEP are stored. In the middle 1960s, two spent cores of NS with LMC "K-27", design 645, were placed in the concrete containers at the CSE Gremikha near the dry dock. Later, they were place in the building 1B. The radiation situation inside the building is normal; the DR is 30-80 μR/h.

The site of the temporary storage of the SRW is used to store SRW and SFA in containers. The 20 by 15 meter site is enclosed on three sides by a wall 3 m high made of ferroconcrete blocks. The site is located at the highest part of the landscape. By the end of 2001, it contained approximately 900 m^3 of SRW and 91 containers with SFA. The maximum DR at the site is 0.3 R/h.

1.3.2. The Service and Repair Enterprise "Atomflot"

The service and repair enterprise (SRE) "Atomflot" was established in 1960 within the Murmansk Sea Navigation Enterprise for technical and technological maintenance and repairing of nuclear-powered vessels and nuclear maintenance support vessels (NMSV). It also served as a place of permanent basing of the NMSV fleet (see Table 1.21).

It provides mooring for nuclear-powered icebreakers, lighter carriers, and NMSV. The enterprise has crane equipment powerful enough to carry out transportation and technological operations with fresh and spent fuel, as well as SRW in containers up to 100 tons. There is a railway connection line.

The SRE "Atomflot" has a chamber for storing the fuel assemblies in containers, a compartment for storing the SFA in containers, and two tanks 100 m^3 each to accept LRW for further processing.

The SRW storage building includes a section for storing the extractable parts of the reactors, FA storage, and a closed site for container storage. Near the building, there is the open air site for the SRW storage and the open air extension of the container storage.

The enterprise temporarily stores the following RW produced in course of the exploitation, repair and technical maintenance of the nuclear-powered icebreaker fleet:

- ion-exchange resins;
- extractable parts of reactors;
- control rods;
- metal waste (dismantled equipment, tools, fittings);
- flammable solid radioactive waste (coveralls, rag, wood, plastic compounds); and
- liquid radioactive waste.

The SRE “Atomflot” has:

- storage of high- and medium-active SRW:
- three containers for temporary storing (TSC) of the extractable reactor parts;
- six concrete containers (CC) to store the broken packages with the SF;
- storage of the low-active SRW;
- a closed site for container storage with a volume of 273 m^3; and
- open storage sites with a total area 1500 m^2.

At the SRE “Atomflot”, 274 m^3 of SRW with a total activity 121 kCi (448 TBq) are stored temporarily.

Table 1.21. Disposition of SFA and RW at NMSV of the Icebreaker Fleet [1.94, 1.126]

Vessel name	Number of SFA as of the end of 1998	As of the end of 2000			
		SRW		LRW	
		Volume, m^3	Activity, Ci/TBq	Volume, m^3	Activity, Ci/TBq
Floating servicing enterprise (FSE) “Imandra”	1205	2.8	5.4/0.2	184.7	3/0.11
FSE “Lepse”	640	37.0	7.3/0.27	63.0	18.4/0.68
FSE “Lotta”	3718	---	---	2.6	0.54/0.02
FSE “Volodarskii”	---	324.8	876/32.40	---	---
Special tanker “Serebrianka”	---	---	---	781.2	3.6/0.13
Total	5563	364.6	890/32.87	1031.5	25.54/0.94

1.3.3. Transportation and Technological Chains of SF Management in the Murmansk Region [1.32, 1.34, 1.35, 1.70, 1.74, 1.80, 1.89, 1.94, 1.126, 1.100, 1.108, 1.113, 1.124]

SF Transportation from Murmansk City

The SFA from the storage of the FSE 326M resulting from the defueling cycle of the NS located at the Poliarnenskii ship-repairing plant and “Sevmorput’” plant are reloaded to the storage of the FSE 2020, which, in turn, transfers them through the FSE “Lotta” to the special train [1.32].

The FSE 2020 is not equipped with a container loading section; it transfers the SFA from its storage to the container TK-18 placed at the loading section of the FSE “Lotta” in the water area of the SRE “Atomflot”. The coastal crane transfers the filled container from “Lotta” to the cabin of the special train that carries the SF to the enterprise “Mayak”.

SF Transportation from Gremikha

The coastal servicing enterprise aimed mainly at the reactor refueling of nuclear submarines with LMC is out of operation. The surface transportation lines (railway, road with the required covering) to connect Gremikha with the transport communications of the Kola Peninsula, are absent and were not provided in the design. Only sea vessels can carry out freight handling.

The CSE includes a dry dock aimed at NS docking to refuel its reactors and at transferring on the solid ground spent cores from the FSE storages to those of CSE and vice versa in order to carry SF to train-shipment stations, where they are loaded into the container cabins.

Waterborne defueling of SF from reactors of NS in Gremikha-settlement is dangerous owing to unsatisfactory technical state of the vessels for providing the draught and stability parameters of the NS for the whole period of defueling with the FSE participation.

In addition to SF from nuclear submarines with the PWR reactors, the CSE Gremikha stores the SEP of NS cores with liquid metal coolant.

All nuclear submarines of this type are decommissioned; four units are utilized.

The plan for decommissioning does not include two NS with liquid metal coolant and not unloaded SEP; they have coolant frozen as a result of the unreadiness of the refueling base to unload the SEP. The NS wait for the utilization afloat at the mooring point.

LMC does not add any significant difficulties to the NS utilization process. However, it is necessary to allow for the specific design features of the power reactor facility of this type that affect the related technological utilization processes.

The main difference is the construction of the reactor core, which forms a united extractable part together with the radiation protection lid. Therefore, the procedure of the SF unloading is reduced to the unloading of the spent extractable part (SEP) from the reactor vessel [1.11].

The CSE Gremikha has special equipment for unloading the SEP from the LMC reactors and their further storage. The unloading is performed on solid ground in the dry dock DD-10, which is an integral part of the refueling complex. However, the equipment is obsolete and decommissioned.

The unloaded SEP are stored at the CSE repository; the storage period is not determined. Further unloading is stopped owing to the unsatisfactory state of the DD-10 dock. The utilization problems of nuclear submarines with LMC require additional thorough scientific studies.

At the moment, the scheme of SF transportation from Gremikha-settlement is out of operation.

1.3.4. Transportation and Technological Chains of SF Management in the Arkhangelsk Region

At the moment, there are no SF storage sites in the Arkhangelsk region. The spent fuel appears only in the process of defueling from the utilized NS at the territory of the Federal State Unitary Enterprise (FSUE) “Zvezdochka SMBE” in Severodvinsk.

One of the main factors that determine the radiation potential of the SF defueling is the amount of activity accumulated in SFA of NS under utilization. The amount of activity significantly depends on the operation regimes, in particular, on the level of power production reached and the waiting time following the decommissioning. Therefore, the radiation potential can be calculated assuming defueling of four NS, which results in 2240 SFA annually. Allowing for the calculations of the Experimental Design Office of Machine Building [1.108] related to the analysis of the radiation accidents with the reactor OK-350, we assume that the radiation potential of the defueled SFA reaches ~ 1.9×10^6 Ci.

A part of the SF management cycle of nuclear submarines to be dismantled is performed at the FSUE “Sevmash” and FSUE “Zvezdochka” in Severodvinsk, Arkhangelsk region.

According to the enterprise design, SF unloading is only possible at installation 150 of the FSUE “Zvezdochka”.

The existing cycle of SF handling from NS to be dismantled involves the following technical means and objects:

- floating servicing enterprise (FSE) 2020 (PM-63) for reactor defueling, temporary storage of the SF and its loading into transportation containers (casks) TC-18 (TK-108/1);
- FSE 326M (PM-124) only to accept SF from NS, temporary storage, and transition to PM-63, according to individual joint decisions of the charged departments;
- equipment OK-300РБ and OK-300РБМ to defuel the reactors OK-350 and OK-650, respectively;
- train-shipment point for reloading of SF from PM-63 to the special train in the port of the Belomorsk Navy base; and
- the special train that consists of four cabins TK-VG-18 (3 TK-18 containers in one cabin) owned by the enterprise “Mayak”.

Figure 1.4 presents the existing transportation and technological scheme of SF management in Severodvinsk. Figure 1.5 displays the scheme of SF unloading by FSE.

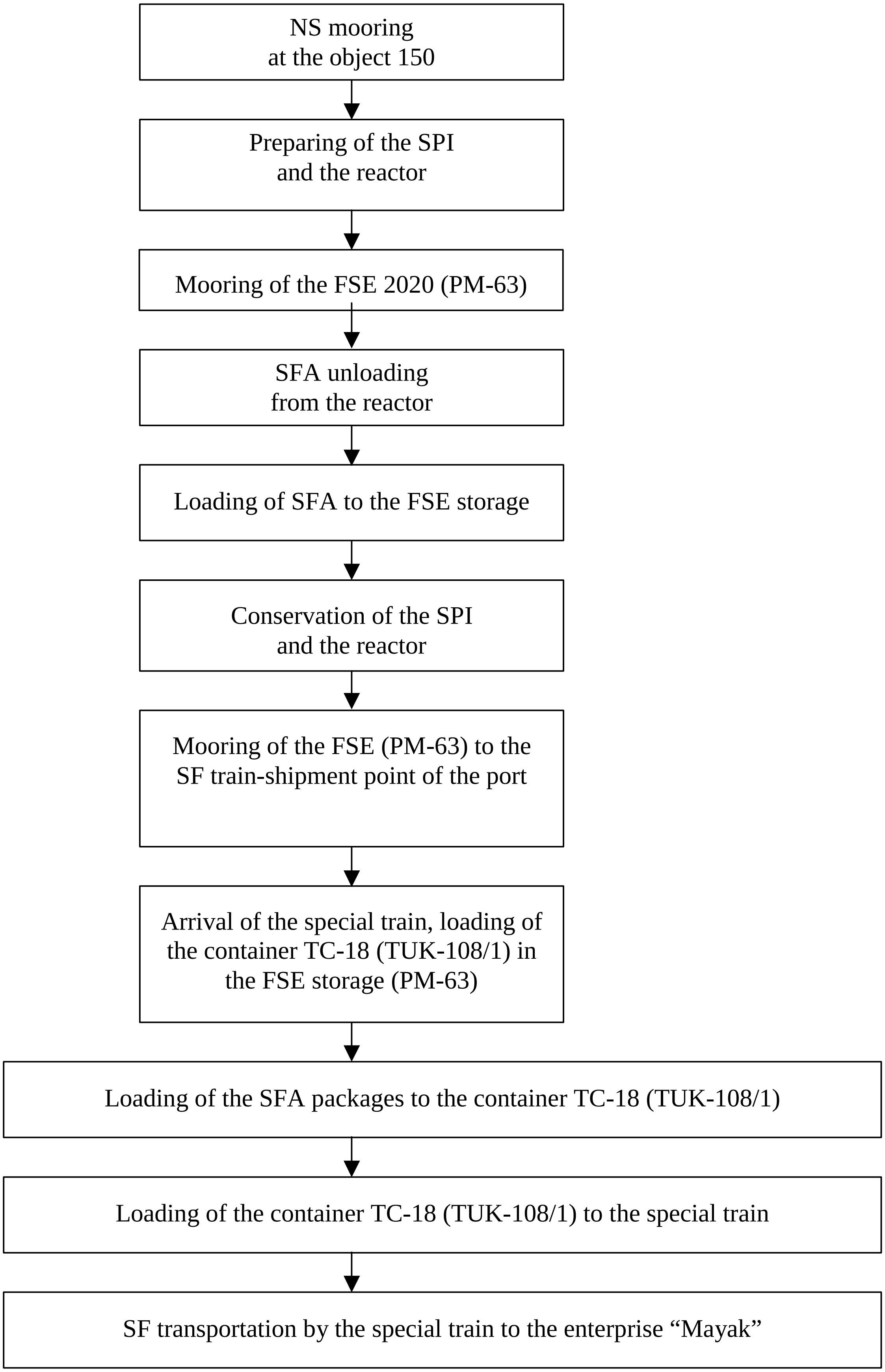


Fig. 1.4. Transport and technological chain of the SF management in Severodvinsk

Scheme of the SF unloading by the floating maintenance base

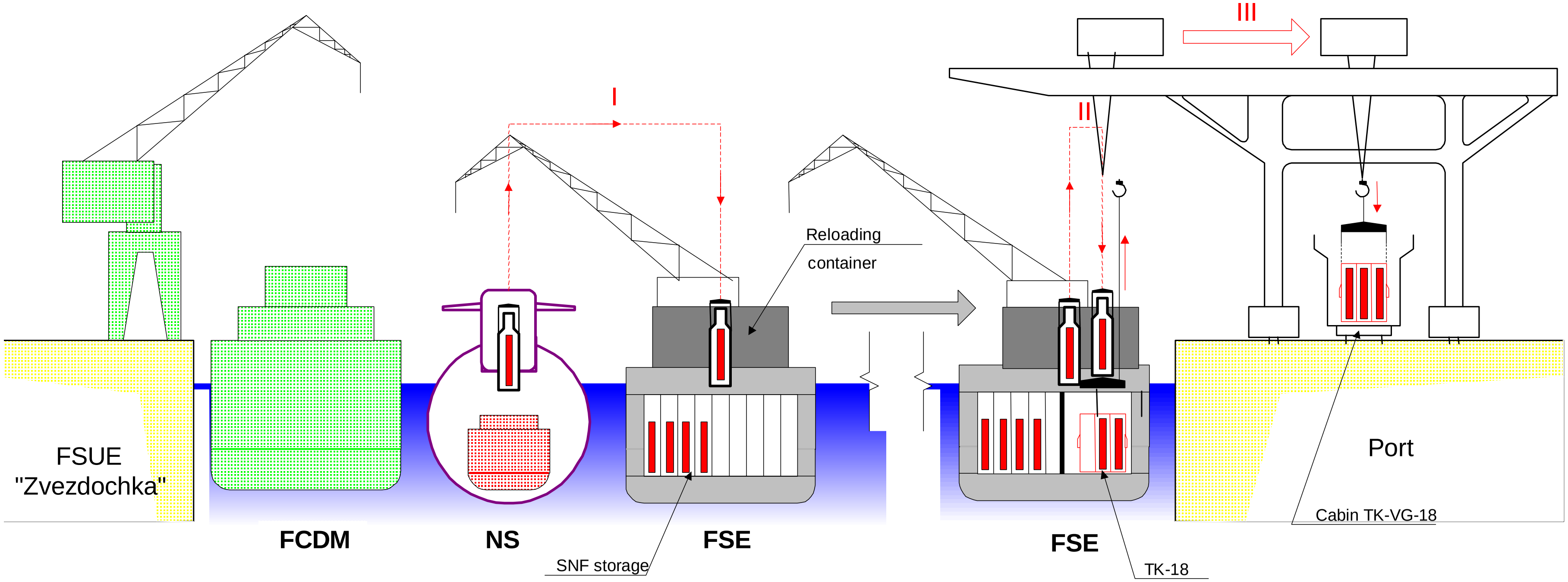


Fig. 1.5.

Currently, the construction of a coastal complex for SF unloading from NS to be dismantled is virtually finished at the FSUE “Zvezdochka”. Commissioning this installation in 2001 will significantly increase the rate of the NS defueling.

The coastal complex includes the following main installations, buildings, and equipment located in the special working zone of the FSUE “Zvezdochka”:

- embankment for the NS mooring;
- gantry crane of 80 ton lifting power, certified for the work with special freight for NS handling and SF loading to the transportation casks;
- building for SF loading to the transportation casks TK-18 (TUK-108/1);
- site for the temporary storage of the transportation casks TK-18 (TUK-108/1) with a 50 ton crane and railway tracks;
- formation section and parking of the special train;
- transportation facilities and tracks for transportation of the casks TK-18 (TUK-108/1) from the loading building to the site of the temporary storage and back (empty);
- power supply sources;
- radiation situation control system;
- OK-300РБУ equipment for SF unloading from NS reactors;
- transportation and packing equipment for loading and transportation of SF; and
- system of physical protection of the buildings and equipment.

Figure 1.6 presents the transportation and technological chain of SNF management using the coastal defueling complex.   Figure 1.7 illustrates the scheme of SNF unloading by the CSE.

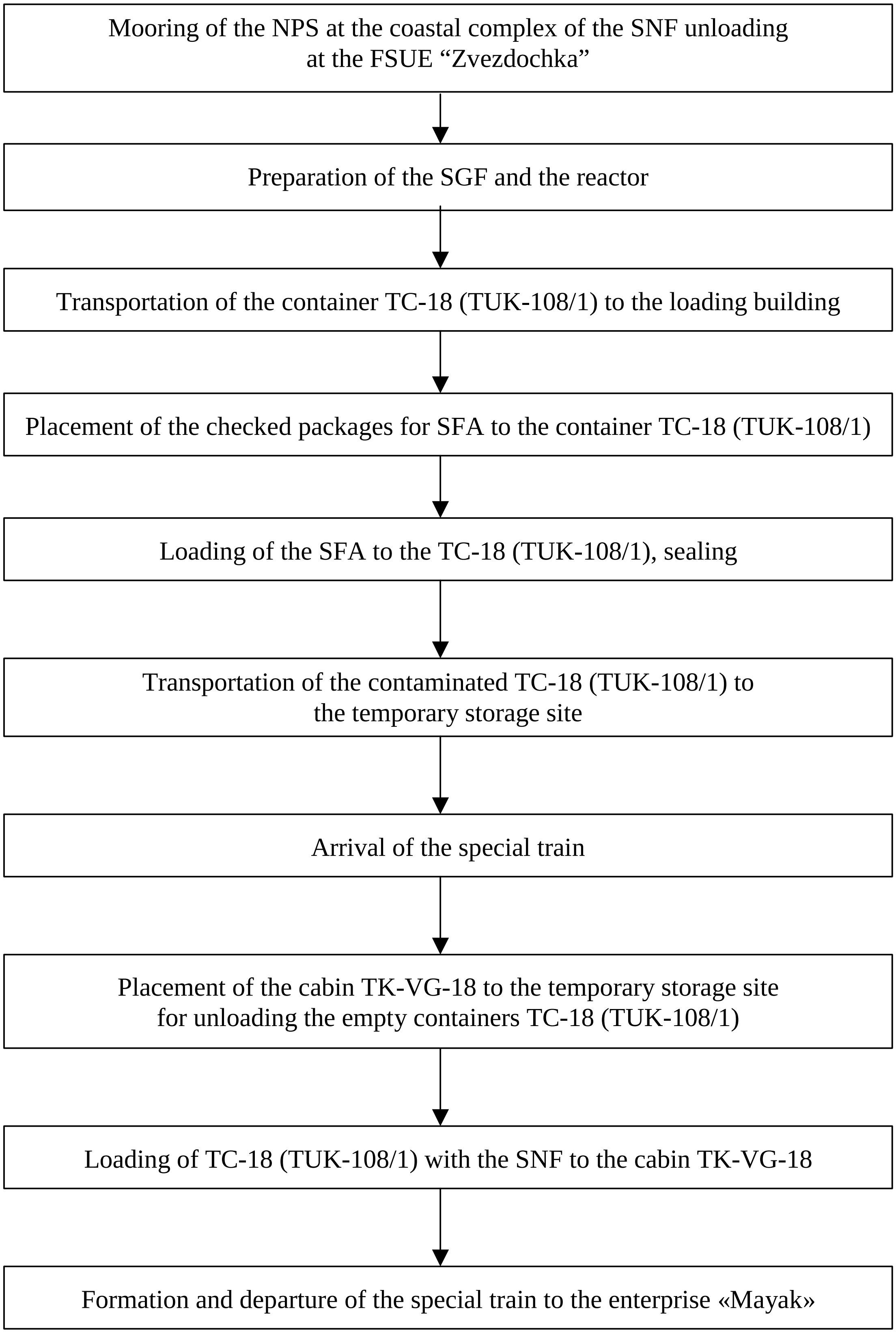


Fig. 1.6. Transportation and Technological Chain of SF Management at the FSUE “Zvezdochka” Using the Coastal Complex of SF unloading from Nuclear Submarines to be Dismantled

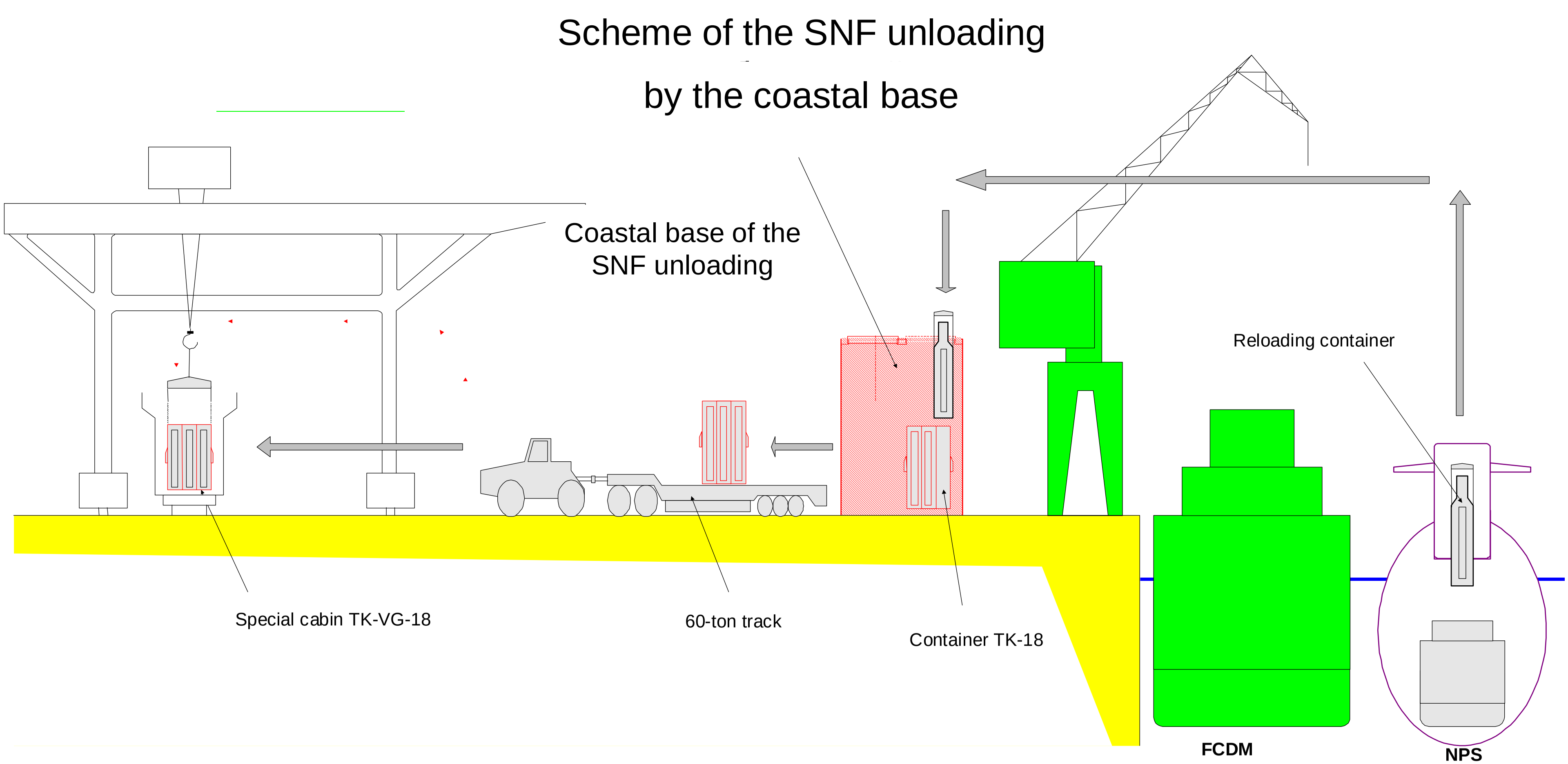

Scheme of the SNF unloading
by the coastal base
Coastal base of the
SNF unloading
Reloading container
Special cabin TK-VG-18
60-ton track
Container TK-18
FCDM
NPS

Fig. 1.7.

1.4. Characteristics of RW, Vessels and Enterprises Involved into the Process of Nuclear Submarine Utilization

1.4.1. LRW and SRW Sources when NS Dismantling [1.34, 1.35]

Within the existing utilization technology, including that applied to NS at the FSUE “Zvezdochka” and FSUE “Sevmash”, the radioactive wastes (RW) are produced at the following stages:

- NS preparation for the utilization and defueling;
- defueling;
- cutting of the three-compartment block with the reactor compartment (RC); and
- preparation of the three-compartment block for temporary storing.

Tables 1.22 and 1.23 display the amount of RW accumulated at the moment in the Northwest region.

Table 1.22. Solid Radioactive Wastes [1.35]

No	SRW storing place	SRW amount, m^3	Total activity, Ci
Arkhangelsk region			
1.	Severodvinsk	2278	1163.5
Murmansk region			
2.	Snezhnogorsk	315.2	175.0
3.	Gremikha	875.5	149.0
4.	Zaozersk	5431.5	
5.	Murmansk	93.75	41.0
	Total:	8993.95	1371.0

Table 1.23. Liquid Radioactive Wastes [1.35]

No	LRW storing place	LRW amount, m^3	Total activity, Ci
Arkhangelsk region			
1.	Severodvinsk	656.2	22.2
Murmansk region			
2.	Snezhnogorsk	1270	8.5
3.	Gremikha	675.3	2.5
4.	Polyarninskii SRY	300	0.27
5.	Navy SRY-10	115	0.02
6.	Navy SRY-35	210	0.4
	Total:	2226.5	33.89

1.4.2. Liquid Radioactive Wastes

The amount and the content of LRW produced in the process of the NS utilization for various designs are presented in Tables 1.24-1.25.

Table 1.24. Amount and Content of LRW Produced in the Process of the Second-Generation NS Utilization

LRW-type	Amount, m^3	Specific activity, Bq/l
Coolant of the primary circuit and technological water of the third circuit (distillate)	78.0	$3.7 \bullet (10^7 – 10^3)$
Spent decontaminating solutions (decontamination of the reactor compartment and technological fittings) (Acid and alkaline water)	4.0	$3.7 \bullet (10^4 – 10^2)$
Technological water from the tanks with contaminated water and the bilge (technical water)	2.0	$3.7 \bullet (10^4 – 10^2)$
Technological water of the biological shield (sea water)	169.5	$3.7 \bullet (10^4 – 10^2)$

Table 1.25 Amount and Content of LRW Produced in the Process of the Third-Generation NS Utilization

LRW type	Amount, m^3	Specific activity, Bq/l
Coolant of the primary circuit and technological water of the third circuit (distillate)	96.0	$3.7 \cdot (10^7 – 10^3)$
Spent decontaminating solutions (decontamination of the reactor compartment and technological fittings) (Acid and alkaline water)	20.0	$3.7 \cdot (10^4 – 10^2)$
Technological water from the tanks with contaminated water and the bilge (technical water)	10.0	$3.7 \cdot (10^4 – 10^2)$
Technological water of the biological shield (sea water)	349.0	$3.7 \cdot (10^4 – 10^2)$

Fig. 1.8 presents the LRW management scheme at the FSUE “Zvezdochka.” Fig. 1.9 presents the LRW management scheme at the FSUE “Sevmash”

LRW Management Scheme at the FSUE “Zvezdochka”

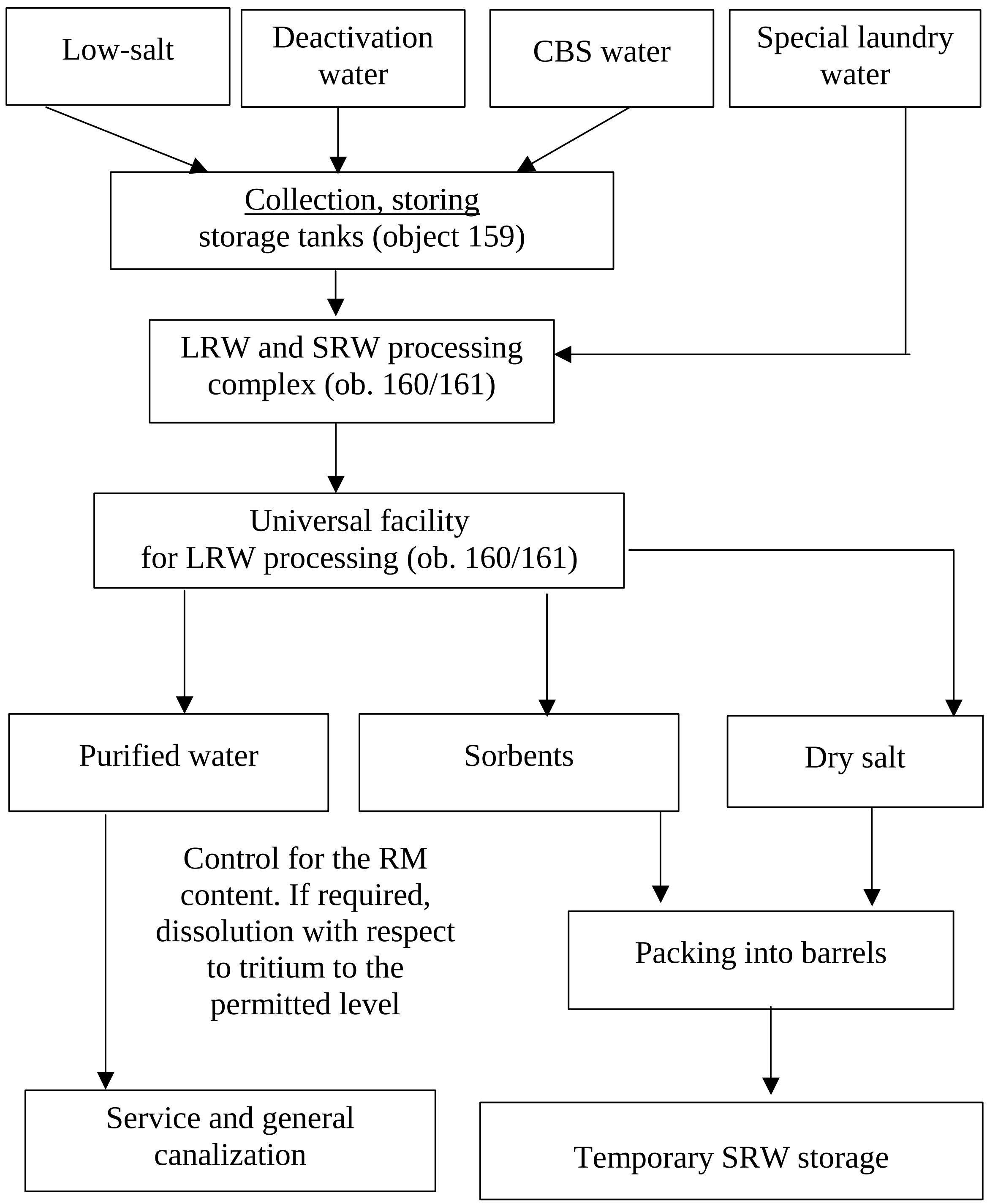


Fig. 1.8.

LRW Management Scheme at the FSUE “Sevmash”

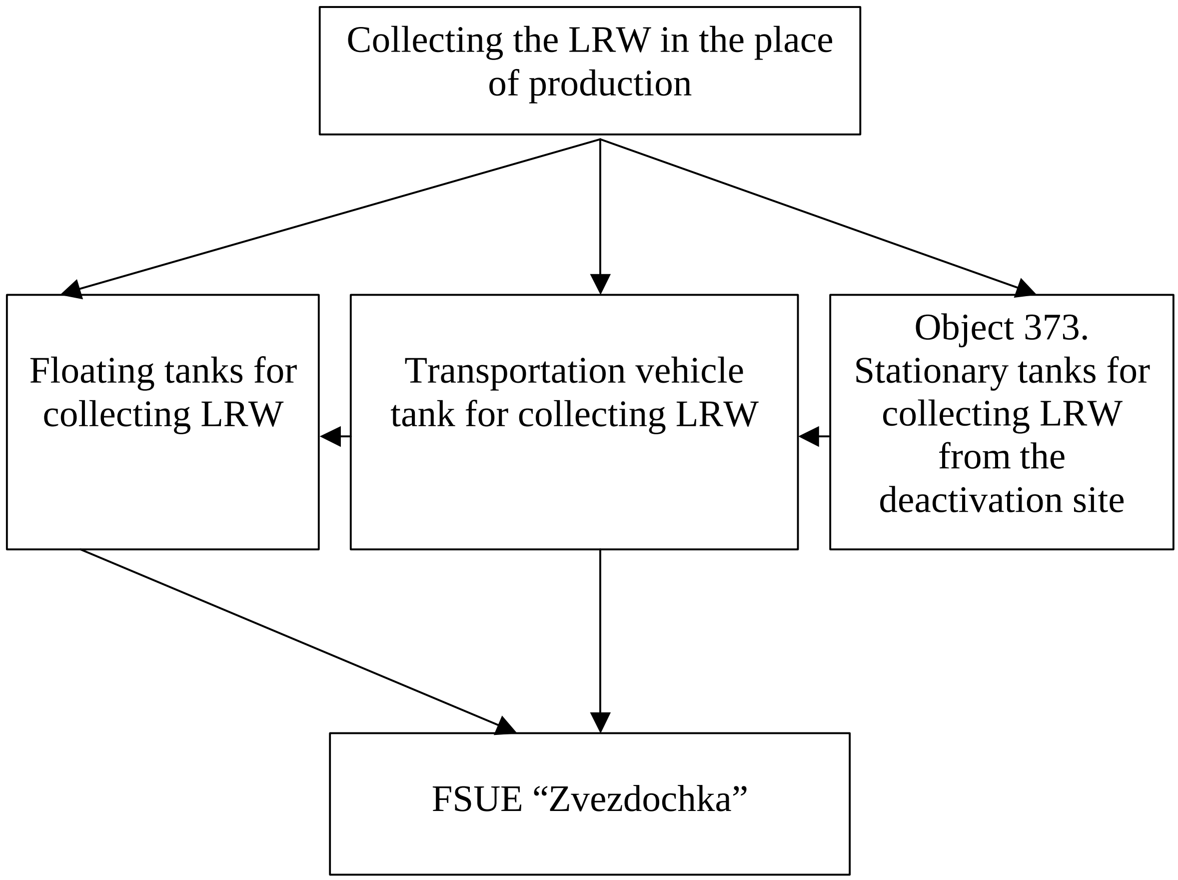


Fig. 1.9

1.4.3. Characteristics of the Operational LRW of NS [1.34, 1.35, 1.65, 1.69, 1.70, 1.72, 1.79, 1.80]

Liquid radioactive wastes (LRW) are produced in course of the ordinary operation and repairing of power reactor facilities, refueling of the reactor core, replacement of the ion-exchange resins in the activity filters, and as a result of cleaning up radiation accident consequences. The wastes produced in the process of the NS utilization form an important part of the total LRW amount.

The volume of LRW produced by the Northern Navy (disregarding the water of the decontamination centers and special laundries) varies from 3500 to 6700 m^3 annually. According to the exploitation experience, 70-90% of this volume are the low-active LRW (below $1 \cdot 10^5$ Ci/L / 0.37 MBq/L). The fraction of the medium-active LRW ($1 \cdot 10^{-5}$ – $1 \cdot 10^{-2}$ Ci/L / 0.37 MBq/L – 0.37 GBq/L) does not exceed 30%. These wastes are produced in such technological operations of NS power reactor facility maintenance as rinsing of the facility circuits, decontamination of the removable and non-removable equipment, sampling of the circuit media and their analysis, replacement of the ion-exchange resins in the activity filters, etc. The high-active LRW (above 1 Ci/L / 37 GBq/L) are not produced by the Navy vessels. The medium-active LRW (above 10^{-2} Ci/L / 0.37 GBq/L) are mainly produced in a case of power reactor facility accidents. The severe accidents and the operations for the elimination of their consequences produce from 400 to 4000 m^3 of LRW; the total waste activity exceeds by the factor 10-100 the total activity of all LRW produced by the Navy NS in course of the normal operation. The total volume activity of the waste in some cases reached 0.3-0.5 Ci/L / 11.1-18.5 GBq/L.

The PWR reactors with sealed fuel element claddings produce wastes dominated by the activation corrosion products (^{58}Co, ^{60}Co, ^{54}Mn, ^{56}Mn, ^{55}Fe etc.). The reactors with depressurized claddings produce a significant portion of long-lived nuclides (^{90}Sr, ^{137}Cs etc.). Usually, plutonium isotopes and transuranium elements are unavailable in LRW of NS power reactor facilities.

A special group of the LRW is formed by sewage water of the decontamination centers and special laundries. Approximately 300,000 - 400,000 m^3 of such wastes are produced annually; their volume activity reaches $1 \cdot 10^{-7}$ Ci/L (3.7 kBq/L). In most cases, the radionuclide concentration in these wastes does not exceed the intervention level established by NRB-99. The sewage water contains a significant fraction of surfactants.

Under ordinary conditions of NS operations, technological media of power reactor facility circuits mainly forms LRW. For various types of the facilities, the amount of the produced LRW per one vessel power reactor facility varies from 40 to 100 m^3. The content of the liquid operational wastes strongly depends on the specific features of the facility design, frequency of coolant recharging, and amount of time waste is held. It includes activation and fission nuclides in various fraction ratios.

Maintenance operations like repairing, refueling of the reactor cores, replacement of the ion-exchange resins in the activity filters, and circuit rinsing produce LRW; the main contribution comes from the decontamination water. The volume of this water significantly exceeds the volume of the operational wastes. Refueling of the active zone produces up to 400 m^3 of the LRW with the volume activity 10^{-8} - 10^{-4} Ci/L (0.37 kBq/L – 3.7 MBq/L). Up to 200 liters of waste are extracted from the activity filters in the process of ion-exchange resin replacement. The volume of radionuclide activity in the spent ion-exchange resin reaches 10^{-5} – 10^{-2} Ci/L (0.37 – 370 MBq/L). With respect to the nuclide content, this type of waste is similar to circuit water and differs mainly by the increased fraction of the long-lived radionuclides (^{60}Co, ^{54}Mn, ^{90}Sr, ^{137}Cs, ^{144}Ce etc.).

Large amounts of the LRW are produced in the process of repairing power reactor facilities of NS. Repairing one PRF produces from 150 to 300 m^3 of LRW, with activity volume from 10^{-9} to 10^{-5} Ci/L (from 37 Bq/L to 0.37 MBq/L). Repairing of the damaged PRF produces wastes, which contain mainly long-lived radionuclides. This is due to a long waiting time prior to damaged vessel repair.

Cooling technological water of coastal and floating SFA storages represents a specific group of LRW. These wastes contain long-lived radionuclides (mainly ^{90}Sr and ^{137}Cs) with the concentration up to 10^{-2} Ci/L (0.37 GBq/L).

Vessel power reactor facility accidents and cleanup of their consequences produce 400-500 m^3 (sometimes up to 1000 m^3) of LRW, with the volume activity up to 10^{-2} Ci/L (0.37 GBq/L) and total activity up to 1 kCi / 37 TBq (Table 1.26).

Table 1.26 Amount of LRW Produced as a Result of Vessel Power Reactor Facility Accidents and the Elimination of their Consequences [1.80]

Waste type	Volume, m^3	Volume activity		Total activity	
		Ci/l	Bq/l	Ci	Bq
Water from the damaged reactor compartment	100	10^{-3}–10^{-2}	10^{7}–10^{8}	100-1000	10^{12}–10^{13}
Decontamination water from NS compartment	150-200	10^{-8}–10^{-7}	10^{2}–10^{3}	10^{-3}–10^{-2}	10^{8}-10^{7}
Decontamination water from the contaminated equipment handling	5-10	10^{-8}-10^{-6}	10^{2}-10^{4}	10^{-3}	10^{7}
Laundry water	70-90	10^{-9}-10^{-8}	10-100	10^{-3}	10^{7}
Shower water from the decontamination centers	70	10^{-9}	10	10^{-4}	10^{6}

Approximately 30% of the LRW produced at the Navy installations consists of low-salted water (draining water of the 1, 2, and 3 circuits); the remaining 70% are salt decontamination water.

LRW, produced during partial draining of the primary circuit, as a result of sampling and decontamination of the equipment, are collected to the draining tanks. Depending on NS design, the vessel has two or four tanks with a total volume of 3 to 8 m^3. LRW from NS are removed to special vessels, floating tanks or special coastal buildings.

In order to exclude unauthorized releases of LRW from the draining tanks of NS, the outlets of the tanks are sealed. The radiation safety service (RSS) is responsible for the state of the seals.

Water from the tanks of the biological shield is removed, depending on their volume activity, either outboard (by permission of the RSS) or to the special storages.

1.4.4. Solid Radioactive Wastes

The amount and content of SRW produced during the utilization of various-design NS are presented in Tables 1.27 and 1.28.

Table 1.27 Amount and Content of SRW Produced in the Process of the Second-Generation NS Utilization

SRW-type	**Amount, m^3**	**Contamination level, β particles/(cm^2·min)**	**Specific activity, Bq/kg**
PRF equipment (metal constructions, pipelines etc.)	8.0	Over 50	Over $7.4 \cdot 10^4$
Insulating coverings, individual protection means, cork, asbestos texture, etc.	1.5	Up to 50	Over $7.4 \cdot 10^4$
Cable pieces, draining pipes of the contaminated water, gum covering, plastic compound, etc.	20	Up to 50	Over $7.4 \cdot 10^4$

Table 1.28 Amount and Content of SRW Produced in the Process of the Third-Generation NS Utilization

SRW type	**Amount, m^3**	**Contamination level, β particles/(cm^2·min)**	**Specific activity, Bq/kg**
PRF equipment (metal constructions, pipelines etc.)	10.0	Over 50	Over $7.4 \cdot 10^4$
Insulating coverings, individual protection means, cork, asbestos texture, etc.	5.0	Below 50	Over $7.4 \cdot 10^4$
Cable pieces, draining pipes of the contaminated water, gum covering, plastic compound, etc.	20.0	Below 50	Over $7.4 \cdot 10^4$

Fig. 1.10 presents the SRW management scheme at the FSUE “Zvezdochka”. Fig. 1.11 presents the SRW management scheme at the FSUE “Sevmash”

SRW Management Scheme at the FSUE “Zvezdochka”

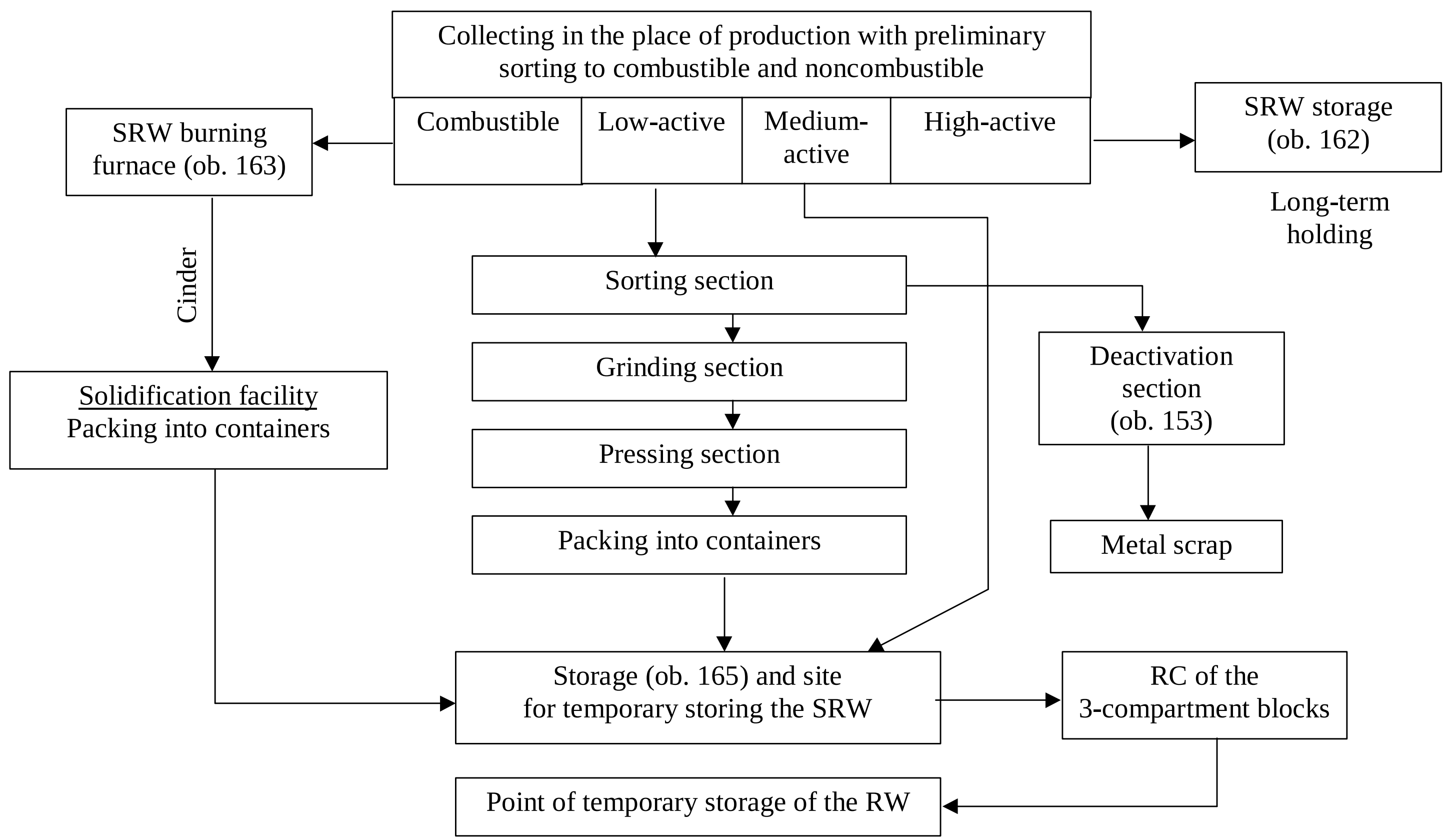


Fig. 1.10

SRW Management Scheme at the FSUE “Sevmash”

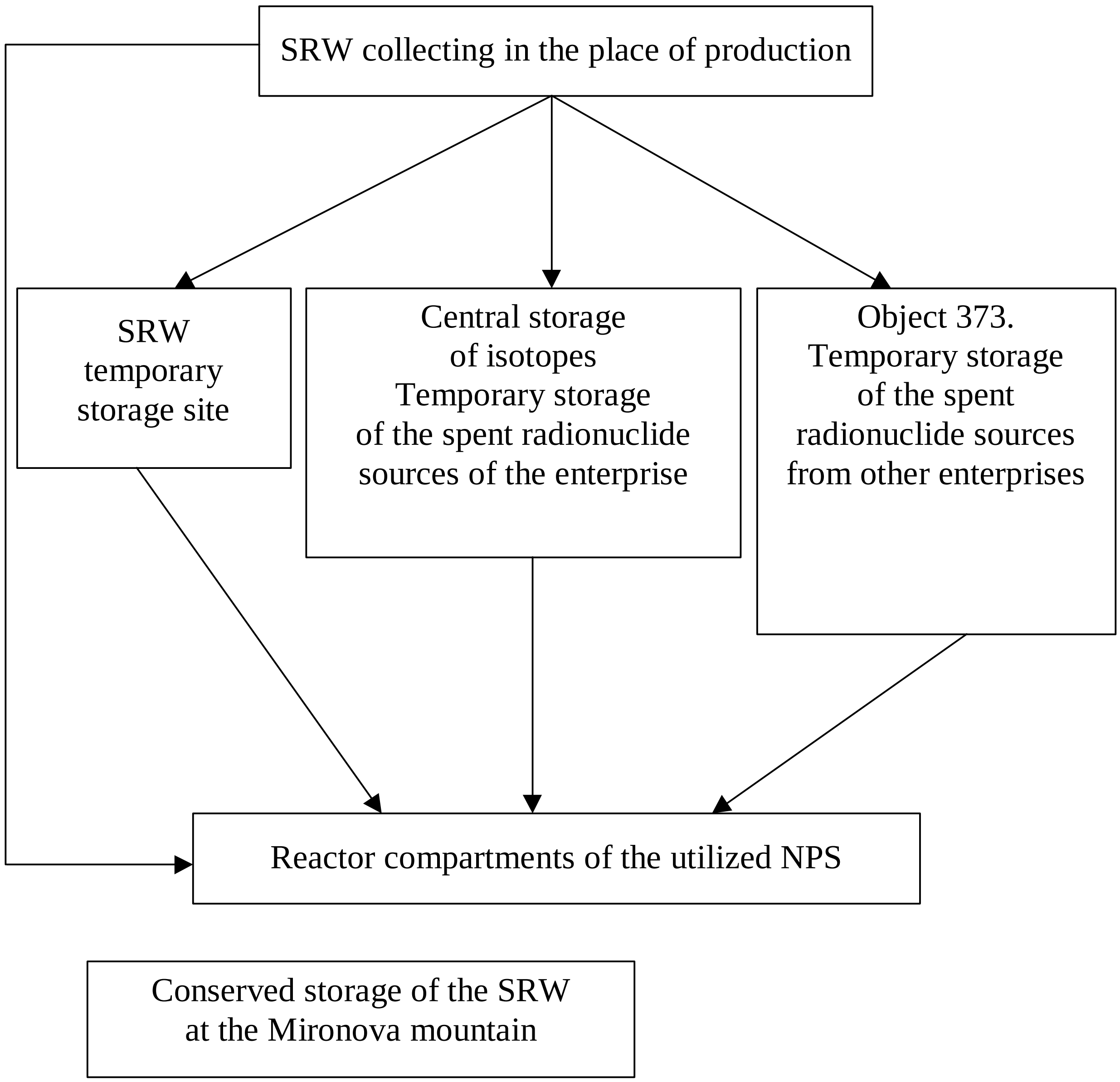


Fig. 1.11

1.4.5. Characteristics of the Operational SRW of NS

Solid radioactive wastes (SRW) of various activity are produced during normal operation conditions and, in particular, during repair operations and accident cleanup.

The SRW group with low specific activity includes the special overalls, means of the individual protection, rugs, tools, lumber, and laboratory glassware.

The SRW group with medium specific activity includes steam generators, pumps, refrigerators and vessels of the activity filters, pipelines, and other equipment of the PRF primary circuit.

The SRW with high specific activity includes the equipment dismantled from the reactor, control and protection rods, and SFA that are not to be reprocessed.

The contaminated large-sized equipment forms an important part of SRW produced during repair operations.

SRW produced in the course of NS normal operations are collected in special cans. The filled cans are transferred to the RSS.

Nuclear submarines also produce gaseous radioactive wastes [1.65]. These are nitrogen and helium from the pressurizer of the primary circuit, and gas from the vacuumization balloons of the equipment compartment baffle. Gas removal from the high-pressure system is forbidden when the NS is at the base. Special filters clean air in NS compartments by removing radioactive aerosols and the vapors of the radioactive iodine. No release of the radioactive materials to the atmosphere occurs in normal operation conditions of NS.

1.4.6. Areas of Storing and Reprocessing of the Radioactive Wastes Produced during NS utilization

1.4.6.1. Characteristics of the Main Installations Dealing with LRW Handling at the FSUE "Zvezdochka" [1.78]

Installation 159, external storages of the LRW, has:

- 4 storages, each 500 m^3 for separate storage of low-active LRW of different types;
- 4 storages, each 500 m^3 for storing the purified solutions; and
- 2 storages, each 100 m^3 with concrete protection for storing the medium-active LRW.

In 1998-1999, the following facilities at the installation 159 and the special channel were repaired:

- 4 storages, each 500 m^3; one storage was covered by a special mastic to store salt LRW;
- storage of 100 m^3 for medium-active LRW;
- special channel with pipelines and control panel at the embankment;
- replacement of pumps, repairing and partial replacement of fittings and pipelines;
- rearrangement of the decontamination center and dosimetric post;
- building interior;
- replacement of the control panel of the technological systems; and
- the stationary system of radiation control was mounted.

The second storage for the medium-active LRW (100 m^3) was not repaired. It contains approximately 50 m^3 of the contaminated sediment, which appeared as a result of using this storage as an intermediate capacity. When the LRW were accepted by the installation 159, contaminated water was settled out in the intermediate storage, and then was pumped into one of the 500m^3 storages. The problem of the sediment management still requires a decision.

The installation is equipped with a modern system of radiation control and environmental monitoring.

In addition, LRW are stored in the "Ossetia" tanker, which was specially designed and constructed to store and transport LRW. "Ossetia" was commissioned in 1963. It has eight tanks, each 125 m^3, to store low-active LRW (up to $3.7 \cdot 10^5$ Bq/L) and one tank of 35 m^3 to store medium-active LRW (up to $3.7 \cdot 10^6$ Bq/L). At the moment, according to the decision of the Inspection of the River Register of Russia (the organization charged with state supervision of the technical state of river vessels), the tanker is in the "mooring" state, that is, the navigation area is restricted to the enterprise territory. Once in every eight years, the tanker "Ossetia" is repaired in the dock and inspected by the Inspection of the River Register of Russia to obtain a certificate for further operations. In these cases, the LRW storage tanks are also repaired. The last dock repair was carried out in 1999. All LRW storages were repaired, and the certificate for the tanker use till 2007 was obtained from the Inspection.

Small amounts of LRW are collected into special stainless steel tanks, 3-4 m^3 in volume, and transported to installation 159 by special truck. The truck body is made of stainless steel; the truck is equipped with a metal shield to protect the driver against radiation.

The complex for the LRW and SRW reprocessing (installation 160/161) was commissioned at the enterprise. It can handle all types of LRW produced at the enterprise, including:

- circuit water produced in the amount ~200 m^3 annually — the distillate containing radionuclides like Cs^{137}, Co^{60}, Sr^{90}, C^{14}, H^3 with specific activity $3.7 \cdot 10^7 - 1.1 \cdot 10^8$ Bq/L;
- sea water from the tanks of the biological shield produced in the amount ~700 m^3 annually, which contains radionuclides like S^{35} with specific activity up to $3.7 \cdot 10^4$ Bq/L; Co^{60} – $3.7 \cdot 10^3$ Bq/L;
- mixed LRW (decontamination solutions, mixed salt solutions) produced in the amount ~600 m^3 annually, having high salt content (up to 20 g/L) and containing radionuclides Cs^{137}, Co^{60}, Sr^{90}, C^{14}, H^3, S^{35} with specific activity $3.7 \cdot 10^4$ – $3{,}7 \cdot 10^5$ Bq/L; and
- special laundry water (washing solutions from laundering and rinsing) produced in the amount ~2500 m^3 annually, containing surface-active substances (SAS) and radionuclides Cs^{137}, Co^{60}, Sr^{90} with specific activity up to $(2.2\text{-}3.7) \cdot 10^2$ Bq/L.

The LRW reprocessing includes concentration of the radioactive isotopes into small volumes and separation of the main mass of water with radionuclide content within the admissible concentration. This complex can process 1500 m^3 of LRW and 2500 m^3 of water from the special laundry annually; as a result, approximately 17 m^3 of SRW are produced.

1.4.6.2. Characteristics of the Main Installations Dealing with LRW Handling at the FSUE "Sevmash PA" [1.78]

The FSUE "Sevmash PA" uses floating tanks to collect, temporarily store, and transfer the LRW to reprocessing. The tanks are transported along the enterprise water area and to the FSUE "Zvezdochka" by the port tugs. Each tank has an operation period of ten years. Between operations, the tanks with the LRW are moored at the special embankment commissioned in 1996. The embankment has:

- a decontamination center with the radiation control point; and
- two concrete platforms for repairing and inspecting the floating tanks.

Up to eight tanks can be moored at the embankment simultaneously. The design volume of each tank is 24 m^3.

Small amounts of LRW are collected in the truck tanks. All LRW are transferred to the FSUE "Zvezdochka" according to the following procedure:

- in summer, by floating tanks and truck transportation tanks; or
- in winter (under heavy ice conditions) by truck transportation tanks.

In view of the established LRW management technology at the enterprise, there is a potential risk from freezing of the floating LRW tanks in winter. There is also the danger of initiating off-normal situations during LRW transportation under heavy ice conditions.

In order to reduce these risks, the enterprise is studying the possibility of storing the LRW in the coastal storages at installation 377.

1.4.6.3. Characteristics of the Main Installations Dealing with SRW Handling at the FSUE "Zvezdochka" [1.78]

Installation 162 was commissioned in 1963. It is a concrete building with the dimensions 42x12x5.8 m, and includes the group of storage chambers that load through the roof. The total volume of the chambers is 1530 m^3. The storage is covered with removable ferroconcrete plates. The walls, floor and the roof of the chambers are made of the reinforced concrete up to 600 mm thick. An electric crane operates at the building. All SRW are divided into the following types: metal (80%), combustible (10%), and trash (10%). According to the design, the installation has an air ventilation system and a fire extinguishing system (injection of carbon dioxide into the chambers).

According to the operational manual, the SRW were loaded to the installation in bulk. The state of the building is unsatisfactory and requires repair.

Installation 165 was built in 1999. The 56.6x12.4x5.0 m building consists of two parts: the storage and the common-purpose part. The storage construction includes the concrete container for the IER filters, a block of concrete containers, and a compartment for the containerized wastes.

All chambers have removable covers for loading and unloading operations. The total volume of the chambers is 2129 m^3. The average filling ratio of the storage is 0.1-0.2.

The site for temporary storing of SRW was commissioned in 1999. The 134x51 m site has asphalt concrete covering and is enclosed by a ferroconcrete fence 2.7 m high. Rain and snowmelt water is collected into cans with further radiation control and removal to the tanks for the LRW collection or to the rain canalization.

The SRW processing will be carried out by the **complex for the LRW and SRW reprocessing** (installation 160/161), which includes the following sections:

- sorting;
- grinding;
- pressing; and
- decontamination.

In order to reduce the volume of soft combustible SRW, the enterprise has the combustion facility with capacity of 40 kg/h at the installation 163. The section was commissioned in 1980 and needs repair and modernization.

The modernization project assumes cooperation with the CEA (France) together with Technicatome. It includes replacement of maintenance systems (fuel supply, gas removal and cooling, ventilation, canalization) and repair of the building interior.

The solid combustion products (cinder) are turned back to the installation 160/161 for further packing in the 200-l barrels and transportation to the site of the temporary SRW storage.

1.4.6.4. Characteristics of the Main Installations of SRW Handling at the FSUE "Sevmash PA"

During the period when the first-generation NS were constructed, the enterprise used the following technology for SRW management: the PRF equipment was partially fragmented; special ventilation filters, individual protection means, and small-sized constructions were packed in polyethylene packages. All SRW were transported to the temporary storage site. Then, the collected portion of the SRW was transported to the SRW storage at Mironova Mountain. It is located 12 km from the dwelling area of the Severodvinsk-town and designed as a near-surface construction.

Owing to the environmental effects and violations of the building technology, the building is filled with water. Because the radionuclides migrate through the walls, the storage is dangerous for the environment and the Severodvinsk population. A decision has been made to decommission the storage.

The site of temporary storage was commissioned in 1992. It includes:

- closed metal storage capable of storing 120 containers;
- an open site to store large-sized equipment;
- the decontamination center; and
- fitting storage.

At the moment, the site does not satisfy the acting regulations on ensuring safety.

1.4.7. Nuclear Maintenance Support Vessels and Shipbuilding(Ship Repair) Yards

Special vessels of nuclear-maintenance support (NMSV) are used to provide technical maintenance of vessel PRF operation [1.63, 1.65, 1.69, 1.70, 1.85, 1.94, 1.126, 1.107]. They include:

- floating maintenance bases;
- vessels for collecting, storing, and transportation of the RW; and
- vessels for SF transportation.

1.4.7.1. Navy Floating Servicing Enterprises

The floating servicing enterprises (FSE) perform refueling (unloading) of the reactor cores; storage of the fresh and spent FA; collecting and storing the RW produced during the core refueling as well as during other operations at FSE.

The Navy uses FSE of two generations. The first generation consists of non-self-propelled FSE of the design 326/326M. During the 1960s, four FSE of this design were built and four more were reconstructed from dry-cargo vessels built in Finland.

As a result of long-term operations (over 30 years) and the lack of repair operations, these vessels are in an unsatisfactory state. Some of them are decommissioned, and others are reassigned as maintenance tankers used for temporary RW storages. Some vessels store damaged SFA. The Arctic Fleet has four first-generation FSE (PM -50, PM -78, PM -124, PM -128 of the design 326/326M). An additional four are assigned to the Arctic fleet.

In 1984, a FSE of the second-generation PM-63 (design 2020) was commissioned and included in the structure of the Arctic Navy. Later, two more FSE of this design, PM -74 and PM -12 were commissioned. PM -12 is also in the structure of the Arctic Navy. These FSE are an improvement over the first-generation FSE. They are self-propelled, the SF storage capacity is increased by a factor of 2.5, they have water purification systems and radiochemical laboratories and they are equipped with modern technological equipment.

All FSE of the Arctic Navy are included in the structures of floating refueling plants. In the 1960s and 1970s, the main FSE berthing areas were the CSE technological embankments. Now, FSE are located at the water areas of the Navy and industry ship-repairing enterprises, which carry out the preparation and auxiliary refueling operations.

These operations are performed upon the removal of the removable plate of the strong NS vessel and dismantling of the reactor upper head. They feature high levels of radiation and radioactive contamination and involve enhanced risk of nuclear and radiation accidents, including spontaneous chain reactions (SCR).

The SF management operations performed at FSE have associated radiation risks (loading, storing, transportation, and transfer of the SFA). Several cases of significant radiation exposure have occurred during these operations at FSE.

The FSE has the following main sources of the ionizing radiation and radioactive contamination:

- SFA;
- equipment extracted from the reactors (control and protection system devices, sensors of the measurement devices, etc.);
- water from PRF circuits, cooling water of the SFA storage;
- spent ion-exchange resins from the PRF circuit water filters from the and water purification system filters;
- water and solutions from the decontamination of the dismantled and reloading equipment.

The decontamination of equipment dismantled from the reactor, replacement of the ion-exchange resins of the activity filters, and rinsing of the PRF circuits produce significant amounts of LRW. These LRW are stored in special tanks of the FSE. The capacity of the tanks at the FSE includes: 450 m^3 of the design 2020 (including 95 m^3 for the LRW with the volume activity up to 10^{-2} Ci/L /$3.7 \cdot 10^8$ Bq/L); and 200 m^3 of the design 326/326M (including 75m^3 for the LRW with the volume activity up to10^{-2} Ci/L /$3.7 \cdot 10^8$ Bq/L).

IER of the activity filters of PRF circuits are unloaded to special traps. The trap volume was 100-l in the first-generation NS and 400-l in the second-generation NS. The volume activity of the fillers is $10^{-5} – 10^{-2}$ Ci/L / $3.7 \cdot 10^5 – 3.7 \cdot 10^7$ Bq/L, the total activity in the trap reaches 1 Ci / 37 GBq. The MAC from the most spent IER traps varies within the interval from 10 to 50 mR/h; sometimes, in particular for the first-generation NS, it reached 500 mR/h.

1.4.7.2. Special Navy Vessels for Collecting, Storing and Transportation of RW

Special vessels are used to collect, store and transport the LRW produced during the exploitation and repairing of the NS and surface vessels with PRF: technical pouring tankers (TPT), technical tankers (TT), and floating tanks. The TT “Amur” and “Pinega” have stations for LRW reprocessing, both of which are shut down owing to operational difficulties. TPT and TT are also used for temporary storage and transportation of the SRW. The total of 17 vessels for collecting, storing, reprocessing and transportation of LRW were built or reconstructed from vessels of other types.

Most of these vessels were commissioned during the 1960s, served for the assumed operation period, and, at the moment, are in an unsatisfactory state. Several accidents occurred with these vessels, including sealing violation and LRW tank leakage. Some TPT were sunk after long and low-effective decontamination (in 1973-74, TPT “Goryn” and TPT-15 without RW in the Kara Sea; in 1988, TPT-14 with LRW of the total activity 17 Ci / 0.63 TBq).

The LRW and SRW stored at the special vessels are the source of radiation and possible radioactive contamination. The tanks of the LRW storage, sections of the SRW storage and the compartments for storing the equipment used in the procedures of loading and unloading of the RW are separated in a strict regime zone (SRZ). The stations of the LRW reprocessing at the TT “Amur” and “Pinega” are also included in a SRZ. The total volume of the LRW stored at the TPT and TT is 880-900 m^3.

Floating tanks PEK-50 are also used for collecting, temporary storage, and transportation of the LRW. The volume of these tanks is 50 m^3. The whole deck and all compartments of the PEK-50 are a strict regulation zone, irrespective of the presence of the LRW. Any activity at the PEK, presence of personnel, and changing of the mooring place require permission of the duty RSS officer. Most of the PEK were commissioned in the 1960s; at the moment, they are decommissioned and stored at the NS bases. Approximately ten PEK are still in operation.

1.4.7.3. Nuclear Maintenance Support Vessels of the Icebreaker Fleet

Technical maintenance of the nuclear-powered icebreaker fleet is provided by the nuclear maintenance support vessels (NMSV) in the structure of the Steamship Company:

- Floating servicing enterprises «Lepse» and «Imandra» are used for refueling of the reactor cores (at the moment, «Lepse» is decommissioned) and temporary storing of SF, LRW, and SRW produced during refueling.
- FSE «Lotta» is used for temporary storage of SF, LRW, and SRW.
- Special tanker «Serebrianka» provides temporary storage and transportation of LRW.
- FSE «Volodarskii» is used for temporary storage and transportation of SRW. At the moment, the base has reconstructed FSE «Volodarskii» for use as floating storage for SRW.

Table 1.29 presents the NMSV characteristics.

Table 1.29. Characteristics of Nuclear Maintenance Support Vessels of the Icebreaker Fleet

No	Name	Building plant	Year of comm	weight, ton	Capacity of the SF storage, number of SFA	LRW tank and its capacity, m^3	SRW storage and its capacity, m^3	Comment
1	FSE “Lepse”	Admiralteiskii	1961	5000	365	№1,-160	no	Mooring order №373/od dated 25.10.90
2	FSE "Imandra"	Baltiiskii	1981	9725	255	ZSR-2,-48, control №1-21, №2-23, pur. water№1-70, №2-19,№3-35, sp.laundry.-39, decon.center-39	no	
3	Floating base"Lotta"	Baltiiskii, reconstruction	1960	7500	12x340	D3,-17	no	

No	Name	Building plant	Year of comm	weight, ton	Capacity of the SF storage, number of SFA	LRW tank and its capacity, m^3	SRW storage and its capacity, m^3	Comment
4	Special tanker "Serebrianka"	"Oka" plant	1974	4000	no	№1,-93; №2,-210; №3,-124; №4,-124; №5,-150; №6,-150	no	
5	Floating base"Volodarskii"	Baltiiskii	1928-reconstr. 69	5500	no	Special tank,-27	2 bilges	Mooring ord. №40/od 30.01.91
6	FCDM "Rosta-1"	Raume Repola	1986		no	no	no	Used as decont.center

NMSV of the icebreaker fleet and the Navy are identical. At the moment, the FSE "Lepse" is used for unloading of SFA.

The NMSV temporarily store the RW produced during the operation of PRF of the icebreaker fleet, their repair and technical maintenance. These wastes include:

- ion-exchange resins;
- extractable parts of the reactor;
- control rods;
- metal wastes (dismantled equipment, tools, fittings);
- combustible SRW (overalls, rugs, lumber, plastic compounds); and
- liquid radioactive wastes.

By the end of 2001, the NMSV temporarily stores 364.6 m^3 of SRW with the total activity 890 Ci/32.87 TBq; and 1031.5 m^3 of LRW with the total activity 25.54 Ci/0.94 TBq.
Table 1.30 presents the location of SFA and RW at NMSV of the icebreaker fleet.

Table 1.30 Location of the RW at the NMSV of the Icebreaker Fleet

Vessel name	As of the end of 2000			
	SRW		LRW	
	Volume, m^3	Activity, CI / TBq	Volume, m^3	Activity, CI / TBq

Vessel name	As of the end of 2000			
	SRW		LRW	
	Volume, m^3	Activity, CI / TBq	Volume, m^3	Activity, CI / TBq
FSE "Imandra"	2.8	5.4/0.2	184.7	3/0.11
FSE "Lepse"	37.0	7.3/0.27	63.0	18.4/0.68
FSE "Lotta"	---	---	2.6	0.54/0.02
FB "Volodarskii"	324.8	876/32.40	---	---
Special tanker "Serebrianka"	---	---	781.2	3.6/0.13
Total	364.6	890/32.87	1031.5	25.54/0.94

1.4.7.4. Actual Condition of Some NMSV

“PM—50” State

Storage tanks of spent fuel assemblies (SFA):

Nose: 20 m^3, specific activity of $2.0 \cdot 10^{-5}$ Ci/L, altogether – $4.0 \cdot 10^{-1}$ Ci;

Stern: 20 m^3, specific activity of $1.9 \cdot 10^{-5}$ Ci/L, altogether – $3.8 \cdot 10^{-1}$ Ci.

Active water storage:

Tanks № 1 and № 2 - empty;

Tank № 3: 20 m^3, specific activity of $3.7 \cdot 10^{-5}$ Ci/L, altogether - $7,4 \cdot 10^{-1}$ Ci.

Decontamination water run-off:

Tank № 1: 20 m^3, specific activity of $6.2 \cdot 10^{-5}$ Ci/l, altogether – $1.24 \cdot 10^{+0}$ Ci.

Tank № 2: 22 m^3, specific activity of $9.6 \cdot 10^{-5}$ Ci/L, altogether – $2.11 \cdot 10^{+0}$ Ci.

Tanks of decontaminated waters:

№ 1: 12 m^3, specific activity of $2.3 \cdot 10^{-5}$ Ci/L, altogether – $2.76 \cdot 10^{-1}$ Ci;

№ 2: 12 m^3, specific activity of $3.1 \cdot 10^{-5}$ Ci/L, altogether – $3.72 \cdot 10^{-1}$ Ci.

Integral liquid radioactive waste volume - 126 m^3, integral activity ~ 5.52 Ci.

Data on SFA, rods of the control and protection system (CPS) and solid radioactive wastes (SRW) in FSE repositories and rooms:

- No SFA within “PM” repositories;
- There are 14 containers with high-activity CPS rods; and
- Containers with SRW are placed on the upper deck and in the decontamination room (integral volume of containers – 79.5 m^3, integral activity – 7.8 Ci).

Within the coastal zone of the CSE in Andreeva Bay, 14 submerged vessels are located across the Bay from the SRW site. Some of them were used to temporarily store LRW. The radiation survey has demonstrated that equivalent dose rate values on vessel decks vary from 50 to 500 μSv/h, whereas β-contamination of outside surfaces makes up 100 — 300 disintegrations/$cm^2 \cdot$min.

In CSE of Iokon’ga Gulf (Gremikha settlement), over 10 floating tanks (FT-50) are stored in afloat conditions. Data measurements made in 1999 on the radiation situation (DR on the upper deck) for 4 FT are available:

- FT-167 5 - 13 μSv/h;
- FT-175 0.1 - 0.3 μSv/h;
- FT-986 5 - 13 μSv/h; and
- FT-991 10 - 14 μSv/h.

For FT-167, there is LRW with specific activity of $1.5 \cdot 10^{+3}$ Bq/l.

There are no data on the radiation situation for the remaining vessels of FT class.

Floating tanks of the FT-150 type can receive 50 m^3 of LRW of $1 \cdot 10^{-5}$ Ci/L specific activity at the most.

Tanker TPT-8 was decommissioned in 1989 and half-submerged near Zajachij Island (Pala Gulf, Poliarny town). Data on liquid and solid radioactive wastes as well as on the radiation situation as a whole are unavailable.

1.4.7.5. Actual Radiation Situation at FSE

Gamma dose rates within almost all "PM-50" compartments do not exceed admissible limits in force: for strict regime zone (SRZ) - 29 μSv/h; for habitable rooms – 0.72 μSv/h; and for the remaining rooms of free regime zone (FRZ) – 2.16 and 10.8 μSv/h.

There are only small areas within individual rooms wherein gamma DRs exceed the admissible limits provided in the design (see Table 1.31).

The observed excess (especially in the decontamination room) can result from the impact of containers with SRW. An insignificant excess within the fire-room can be due to the presence of a small SRW quantity (contaminated instruments, equipment, etc.) in a storeroom for hose and auxiliary equipment.

Table 1.31 Areas of Elevated Gamma Dose Rate Values (P_γ)

Level	**Room or area**	**P_γ, μSv/h**	**Admissible limit, μSv/h**
Lower deck	Damaged nose post, FRZ	4.9	2.16
	Room of testing devices of CRS, FRZ	7.3	2.16
	Decontamination room, SRZ	138.0	29
	Storage of fuel channels with fuel, SRZ	39.6	29
	Pipe corridor close to active water repository, SRZ	30.3	29
Platform	Decontamination room,	349.0	29
	SRZ	175.0	29
	Fire-room, FRZ	2.3	2.16
Hold	Pump-room, SRZ	78.0	29
		34.0	29
		51.6	29

The value of surface β-contamination in rooms does not exceed 50-100 disintegrations/cm^2·min (except the SFA storage room – up to 8000 disintegrations/cm^2·min and the heat control sensor room – up to 400 disintegrations/cm^2·min). These values are below admissible contamination levels of work surfaces, skin, working clothes and individual protectants regulated by RSS-99: 2000 and 10000 disintegrations/$cm^2 \cdot min$ for rooms of permanent and periodic personnel presence, respectively. FRZ falls into the first room-type category, SRZ into the second.

1.4.8. Shipbuilding & Ship-Repairing Yards and CSE

1.4.8.1. General positions

Nuclear-powered vessels were built at the shipbuilding yards of the Ministry of the Shipbuilding Industry of the USSR (PA “Severnoe Mashinostroitel’noe Predpriyatie” (PA “Sevmash”), PA “Leningradskoe Admiralteiskoe Ob’edinenie (PA LAO), PA “Baltiiskii Sudostroitelnyi Zavod (PA «Baltiiskii zavod»). Their repair and reconstruction were performed by the ship-repairing yards (enterprise “Zvezdochka”, ship-repairing yard “Nerpa”).

At the moment, owing to the reduction of the shipbuilding program in the Russian shipbuilding agency (successor of the Minsudprom), NS are built only at the PA “Sevmash”; NS repair and utilization are performed by the FSUE “Zvezdochka”, SP “Nerpa”, and PA “Sevmash”.

PA “ Sevmash” was established in 1936 in Severodvinsk-town (Arkhangelsk region). At the moment, it is the only plant in Russia that builds NS. The PA “Sevmash” is also charged to perform the utilization of NS of the designs 705 and 705K. In addition, the plant constructs the derrick platforms for “Gazprom” and civil vessels.

The plant No. 893 (now FSUE “Zvezdochka”) was commissioned in 1954 for repair and modernization of submarines and surface vessels. At the moment, it is the leading enterprise for the utilization of the strategic NS in the northern region. In addition, the enterprise performs machine building for ships. Owing to the reduction of Navy orders, the enterprise started civil shipbuilding and repairing, and also participates in the construction of derrick platforms.

Fig.1.12. PA “Severnoe Mashinostroitelnoe Predpriyatie” (PA “Sevmash”)

Fig. 1.13. Federal State Unitary Enterprise “Zvezdochka”

The ship-repairing yard "Nerpa" (SRP "Nerpa", Snezhnogorsk, Murmansk region) was commissioned in 1970 for repairing NS and Navy vessels. It is located at Kut Bay of the Kola Gulf, 30 km to the northwest of Murmansk. In 1994, "Nerpa" became the main enterprise of the Kola Peninsula for NS utilization. Currently, the plant also builds and repairs civil ships.

1.4.8.2. RW Being Generated at Shipbuilding and Ship-Repairing Enterprises

The enterprises of the Russian Agency for Shipbuilding annually produce 1300 m^3 of LRW, 2500 m^3 of SRW, and approximately 50000 m^3 of water from special laundries and decontamination centers. In addition, 1500-2000 spent radioisotope sources used in defectoscopy and as parts of various radioisotope devices and radiation control tools are produced.

Construction and testing of one NS produces, on average, 2 m^3 of LRW with the specific activity 0.008 µCi/L (0.3 kBq/L) and 23 m^3 of SRW with the specific activity 3-8 µCi/L (0.1-0.3 MBq/L). Repairing of one NS produces 200 m^3 of the LRW with the specific activity 0.015µCi/L (0.5 kBq/L) and 100-150 m^3 of SRW with the total activity 0.3-0.5 Ci (10-15 GBq). Utilization of one NS produces 150 m^3 of LRW with the specific activity 0.008-0.015 µCi/L (0.3-0.5 kBq/L) and approximately 200 m^3 of SRW with the total activity 0.3-0.5 Ci (10-15 GBq).

The LRW contains the following radionuclides [1.2]:

- ^{54}Mn 3 - 5%
- ^{60}Co 5 - 10%
- ^{90}Sr 10 - 12%
- ^{137}Cs 50 - 70%
- ^{134}Cs 5 - 10%
- transuranium elements (when repairing NS with depressurized cores).

From the total amount of SRW, approximately 20-30% is the large-sized equipment (steam generators, pumps, etc.); 50-70% is small-sized equipment, details, and metal scrap; and 5-10% is combustible SRW (rugs, lumber, etc.).

The SRW contains the following radionuclides:

- ^{54}Mn 3 - 5%
- ^{60}Co 10 - 15%
- ^{90}Sr 10 - 12%
- ^{137}Cs 60 - 70%
- ^{134}Cs 3 - 5%

The RW management is performed according to the requirements of the acting sanitary regulations for the RW handling and the industrial rules. The LRW produced as a result of production activity are collected and temporarily stored at the coastal or floating tanks; later, they are transferred to the Navy. Water from the decontamination centers and special laundries are collected in special tanks, dissolved if required, and released to the canalization. The produced SRW are sorted in the place of their production with respect to activity, dimension, and type of the wastes. The sorted SRW are placed in the metal containers 3 m^3 in volume and transported to the temporary storage site. The SRW from the temporary storage site are transferred to the Navy. The SRW from the utilized NS are loaded into the reactor compartments.

Owing to these reasons, the shipbuilding and ship-repairing yards of the Minsudprom and its successor (Russian Agency for the Shipbuilding) did not accumulate significant amounts of the RW. By now at the PA “Sevmash” [1.2]:

- no SF is available; some fresh fuel is present, and it is temporarily stored for further loading to the NS reactors;
- the enterprise has four floating tanks for collecting, temporary storage, and transportation of RW. Each tank has two cans, 11.9 m^3 each, to store LRW with the specific activity up to 10 μCi/L (0.37 MBq/L);
- the enterprise has four tanks of 6.3 m^3 each for collecting the decontamination water. As of April 1, 2000, they contain 6.205 m^3 of the decontamination solution with the total 25.4 μCi / 0.94 MBq;

- there are two tanks, 2.25 m^3 each, to collect the LRW produced by the radiochemical laboratory; and
- the SRW are collected in 1.7x1.4x1.3 m (3 m^3) containers made of steel 35 mm thick and stored at the site of the temporary SRW storage. The large-sized equipment is conserved prior to placing it on the site. The site of the temporary storage was commissioned in 1991 and includes:
  - Storage (of the hangar type) 170 m^2 square with ferroconcrete floor;
  - Special open site 120 m^2 square. As of April 1, 2000, it stores 120 m^3 of the SRW (40 containers) with the total activity 1.57 Ci / 58 GBq and two large-sized units (pumps of the primary circuit) weighing 1.2 t with the total activity 0.38 Ci/14 GBq;
  - In addition, the long-term storage of the SRW is located 12 km to the southwest from Severodvinsk near Mironova Mountain. The total volume of the storage is 1800 m^3, it was commissioned in 1961. The storage chambers were loaded in bulk; they contain 120 m^3 of SRW with the total activity 16.7 kCi / 620 TBq. In 1991, the storage was opened for checking; it was found that some chambers are filled with water with the specific activity 0.0223 μCi/l (0.825 kBq/l). The survey of the storage territory in 1996 showed that the radioactive contamination level of the storage site and the neighboring territories does not exceed the levels established by the RSS-99 for the population.

The NS with the SNF on board wait for repair and utilization at the enterprise water area.

Annex for Chapter 1.4.

Additional Measures to Improve the System of SRW Management at the FSUE “Zvezdochka”

1. Station of Temporary Storage (TSS) of Reactor Compartments (Estimated Project Cost $79.71 million)

It is suggested to construct a temporary storage station (TSS) of reactor compartments at the FSUE “Zvezdochka”. The TSS should include:

- sites for temporary storage of reactor compartments (RC) with covering;
- roads for the RC transportation from the dock chamber to the TSS and from the TSS to the embankment;
- transfer terminal (two sections of the embankment);
- transportation system comprising self-propelled modules with the total carrying capacity 1680 kg; and

- transportation ship for the transportation of the one-compartment units to the area of long-term storage.

Construction of the TSS as an integral part of the NS utilization system will result in:

- implementation of a more effective utilization method;
- ceasing the dangerous storage of reactor compartments “on float”; and
- improvement of the radiation situation in the Northwest region.

2. Section of the SRW Combustion (Estimated Project Cost $1.55 million)

The facility for combustion of the SRW has operated at the FSUE “Zvezdochka” since 1983. At the moment, reconstruction of the facility is required.

The French company “Technicatome” elaborated technical solutions for modernization of the facility allowing for modern regulations and requirements, and taking into account the gained international experience of waste combustion. These decisions include optimal layout of the section compartments; repairing and modernization of the furnace system with the replacement of obsolete equipment by modern models; and implementation of the radiation control system. One of the most important improvements is the necessary implementation of a system for conditioning of the cinder residue by including it into a concrete matrix. The system for collecting the liquids (scrubber solutions, water of the coolant system, water from the cementation process, rinsing water) produced during the system operation is would be put under controls for the radionuclide and chemical content of the liquids.

The modernization of the SRW combustion section would result in:

- safe and reliable operation of the facility owing to duplication of the most important devices (filters, ventilators), which provide environmental protection in case of failure of an individual device;
- reduction of the SRW volume (both accumulated and annually produced);
- reduction of the exposure doses and improvement of the facility personnel working conditions; and
- improvement of the radiological situation owing to the reduction of the radionuclide release into the atmosphere and water objects.

3. Rehabilitation of the SRW Storage Installation162 (Estimated Project Cost $0.843 million)

Installation 162 (temporary storage of the SRW) has been in operation since 1963; at the moment, 80% of the installation capacity is filled with the SRW of low, medium, and high activity levels.

Owing to the effect of the environmental factors, the building part of the installation is in an unsatisfactory state. Design flaws resulted in the loss of roof integrity and penetration of the precipitation into the installation. The amount of water inside the installation is unknown. At the moment, the contaminated water leaks from the chamber through the cracks in the walls.

The complete “rehabilitation” of the installation is required, including unloading of the accumulated SRW from the installation chambers; inspection of the building construction; repairing and modernization of other installation constructions.

The solution of the installation problems assumes:

- elimination of the emergency state of the installation and its transformation into modern storage for the conditioned SRW with multibarrier protection of the environment (SRW – matrix – package – installation constructions – additional roof – system of the LRW collecting from the installation site);
- reduction of the volume of the accumulated SRW by their reprocessing; and
- reduction of the operational risk produced by the operation of the installation 162.

4. Reconstruction of the Decontamination Section (Estimated Project Cost $2.3 million)

The decontamination section located at the installation 153 is used for the decontamination of the repaired equipment with the annual capacity up to 30 tons. In view of the NS utilization and assumed utilization of the special vessels, the necessity appears to deactivate metal constructions in large amounts (up to 400 tons annually). In addition, the reconstructed section will operate in the technological chain with the section for metal SRW melting; preliminary decontamination is required to reduce the residual activity of the contaminated metal reprocessed at the melting section.

The required reconstruction of the decontamination section (with possible construction of a new building if the existing one would be considered inappropriate) should:

- satisfy modern requirements of radiation safety;
- enhance the production capacity of the section to 400 tons annually with implementation of modern decontamination technologies; and
- create a section for the decontamination of large-sized vessel constructions, which would appear as a result of utilization of the special vessels.

The solution will enable:

- reduction of the volume of large-scale metal SRW, owing to joint operation of the decontamination and melting sections;
- reduction of the activity level of the secondary wastes from the SRW reprocessing by the melting method (slab formation) owing to preliminary decontamination; and
- reduction of the radiological risk from the operation of the existing decontamination section owing to satisfaction of modern requirements of radiation safety upon reconstruction.

5. Section of Metal SRW Melting (Estimated Project Cost $4.31 million)

At the moment, the site of the temporary SRW storage contains large amount of the metal SRW, including large-sized equipment, produced as a result of the implementation of the program of NS utilization and repair. This type of SRW (e.g., pumps, steam generators, fittings, pipeline elements) features large dimensions of individual parts, complex construction, and high contamination level. Despite measures aimed at equipment sealing, it is impossible to prevent completely radionuclide release to the environment.

In order to create a system of multibarrier protection for the environment, it is necessary to solve the problem of containerizing of the metal SRW.

It was suggested to create a section for melting metal SRW at the “Zvezdochka” enterprise in order to solve the problem with the accumulation of the metal SRW.

The solution will enable:

- reduction of the volume of the stored SRW by the factor of 5-8 and their storage in the installations 165 and 162 (upon rehabilitation) in a more compact form, with the increase of the coefficient of the volume usage from 0.1 to 0.4-0.5 and implementation of the multibarrier protection principle;
- conditioning of the metal SRW unloaded from the SRW storage (installation 162) by melting; and
- reduction of the radiological risk by ceasing the contaminated equipment storage at the open site.

Additional Measures to Improve the System of SRW Management at the FSUE "Sevmash PA"

1. Modernization of the Special Embankment for Mooring of the Floating Tanks Collecting LRW (Estimated Project Cost $1 million)

At the moment, the storage of LRW between processing operations and maintenance of the floating tanks is performed at the special embankment.

Initially, steam heated tanks performed collection and storage of the LRW. During winter operation of the tanks, technical difficulties with control of the steam supply resulted in emergency situations (freezing of the heating system, and systems of loading and unloading of the LRW). In order to preclude repeated emergencies, the enterprise constructed three tanks with electric heating.

In order to improve the operations with the LRW, the following work is required:

- repairing of the special embankment where the floating tanks are moored;
- create a system of power supply to heat the tanks in winter;
- create an automatic radiation control system;
- Install an automatic system for control of the amount of loaded and unloaded LRW;
- create a system of physical protection, including the protection against the unauthorized access;
- provide mobile communication equipment for the transportation units that perform the transportation of the LRW; and

- perform modernization of the decontamination center.

The solution will enable:

- reduction of the radiation risk related to the existing technology of the LRW management at the enterprise;
- exclusion of access of unauthorized persons to the floating tanks with the LRW;
- reduction of the probability of stealing the LRW;
- providing prompt information about emergencies with the radiation situation; and
- control of the amount and the circulation of the LRW.

2. Reconstruction of the Installation 377 for Collecting and Storing the LRW between Operations (Estimated Project Cost $6.06 million)

Initially, installation 377 was designed and constructed to collect and temporarily store the LRW. However, according to the concept of the LRW management adopted in the 1970s (RW disposal in the ocean), installation 377 was not used for these purposes.

It was assumed that ten storage units with a total volume 4000 m^3 made of carbon and stainless steel would be used in installation 377. The transfer of the LRW from the embankment line No. 2 to the installation 377 should proceed through pressurized pipelines.

Since the installation is not used according to its design purpose, there are the following problems with the LRW management:

- transportation of the floating tanks with the LRW along the water area in winter raises the possibility of emergency situations;
- there is the potential danger for LRW storage in winter due to failure of the systems of power and steam supply;
- the transportation path of the truck tank with the LRW to the FSUE “Zvezdochka” runs through the city territory; and
- the absence of the possibility of the LRW reprocessing results in an unjustified accumulation of the RW.

The commissioning of the installation 377 requires the following operations:

- inspecting and troubleshooting of the tanks for the temporary LRW storage;
- creation of the pipeline for the LRW loading from the mooring line No. 2;
- creation the system of the internal communications;
- installation and tuning of the pumps;
- installation of the system of mechanical filters;
- creation of a compact facility for the LRW reprocessing with an annual capacity of approximately 500 m^3;
- creation of a system of automated radiation control;
- creation of a system of access to the sanitary regime; and
- creation of a system for automated accounting for the RW.

The solution will enable:

- reduction of the RW volume;
- reduction of the radiological risk related to the existing technology of the LRW management at the enterprise owing to satisfaction of modern requirements for radiation safety;
- reduction of the probability of stealing LRW owing to the implementation of modern technologies of the LRW management;
- exclusion of the unauthorized access to the LRW;
- providing prompt information about emergencies and the radiation situation; and
- control over the amount and circulation of the RW.

3. Reconstruction of the Site for SRW Temporary Storage (Estimated Project Cost $8.03 million)

The site of the temporary storage of the SRW was commissioned in 1992.

The site includes:

- closed metal storage capable of storing 120 containers;
- open site for the large-sized equipment;
- decontamination center; and
- fitting storage.

At the moment, the site of SRW temporary storage does not satisfy the regulations. The site capacity is insufficient to solve the problems of SRW storage while allowing for the program of construction, repairing, and modernization of NS and surface vessels with PRF.

The reconstruction of the site of SRW temporary storage includes:

- increasing the installation area by 50%;
- installing an additional 50-ton crane for loading and unloading of the SRW produced as a result of utilization;
- purchasing of a lift truck to transport the containers along the site;
- creating surface storage for high-active wastes;
- site planing and covering by weakly absorbing material;
- creating a section for waste sorting and primary processing, including grinding, pressing, and containerizing;
- installing an automated system of radiation control;
- creating a system of physical protection, including protection against unauthorized access;
- providing mobile communication equipment to the transport units performing the transportation of the SRW; and
- installing an automated system for accounting for the amount of loaded and unloaded SRW.

The solution will enable:

- reduction of the RW volume;
- reduction of the radiological risk related to the existing technology of LRW management at the enterprise owing to satisfaction of modern requirements for radiation safety;
- exclusion of unauthorized access to the SRW and, as a result, reduction of the probability of the SRW stealing;
- providing prompt information about emergencies and the radiation situation;
- control over the amount and circulation of the RW; and
- the capability to store high-active wastes.

4. Liquidation of the SRW Storage at Mironova Mountain (Estimated Project Cost $0.68 million)

At the moment, the SRW storage at Mironova Mountain is a dangerous installation with respect to radiation contamination of the environment and exposure of the population. The primary danger of the activity release to the environment is related to the storage flooding. The secondary danger is the activity release owing to soaking of the ground near the installation – either to the building pit or directly to the surface near the concrete pools. Therefore, it is necessary to transform the storage into an ecologically safe installation.

It is necessary to take into account that the Northwest region of Russia has no facilities for RW burial, and there are certain problems with the waste transfer for more distant burial. Allowing for the recommendations of VNIPIPT of the Minatom of Russia and the result of the ecological expertise of the business plan for storage liquidation, the FSUE "Sevmash" decided to liquidate the storage in two steps:

Step 1 – implementation of some acute measures to transform the storage into an ecologically safe installation for relatively long-term storage; and

Step 2 – liquidation of the storage of the variant "green lawn" upon commissioning of the regional long-term facility for burying the RW.

Upon the implementation of the acute measures (Step 1), the storage can be an ecologically safe installation for next 50 years. It would have virtually no negative effect on the population and would not produce any radioactive contamination of the environment.

1.5. Sources of the Non-Radioactive Contamination Appearing in the Process of NS Utilization

1.5.1. Assessment of the Toxic Product Yield in the Process of Utilization of various NS types [1.2, 1.10]

When utilizing nuclear submarines, non-radioactive contamination appears at the stage of preparatory operations and in the utilization process itself. The main sources of possible contamination of the environment are:

- working liquids of the systems and devices;
- construction materials;
- technology of the preparation and dismantling; and
- system of managing spent media, dismantling materials of the vessel, vessel constructions, pipelines, equipment, and mechanisms.

The main sources of atmospheric pollution are gas cutting and air-arc shaving, used to clean the cutting line from paint and varnish coverings in the process of vessel dismantling [1.13, 1.14].

Mechanical cleaning of the cutting line results in the release of the fine dust from the paint and varnish covering and from the metal of the dismantled construction. The dust content is determined by the type of the paint-varnish covering and the type of the construction metal and includes lead (for priming 81 and 83), manganese, copper, and nickel. The total release is calculated according to the existing regulating documents. Table 1.32 displays the total releases for various designs of the NS.

Table 1.32 Total Releases for Various-Design Nuclear Submarines [1.11, 1.12]

NS Design	**Solid component, kg**				
	Total amount	**Including**			
		Manganese	**nickel**	**Lead**	**copper**
NS of the second generation	599	19.2		0.8	0.8
NS of the second generation	599	19.2		0.8	0.8
NS of the third generation	958	35.5		3.66	15.87

The gas cutting and air-arc shaving result in the production of the aerosols containing:

- gas component – carbon and nitrogen dioxides; and
- solid component – oxides of manganese and chrome, nickel, copper, aluminum, and iron.

The total aerosol release is calculated according to the regulating documents. The specific normative for the AK steel is established experimentally. Table 1.33 displays the total releases for various NS designs.

Table 1.33 Total Releases for Various-Design Nuclear Submarines

Design	**Solid aerosol component, kg**								**Gas aerosol component, kg**		
	Total amount	**Including**							**Carbon oxide**	**Nitrogen dioxide**	**Fluorine**
		Manganese	Chrome oxide	Chrome anhydride	Nickel oxide	Aluminum	Copper	Lead			
NS of the second generation	1603.009	64.968	2.959	11.18	2.924	0.408	3.798	0.5	365.123	243.176	1.959
NS of the second generation	1948.48	66.33	1.125	2.72	3.525	0.24	4.655	1.3	389.2	315.8	1.788
NS of the third generation	5187.75	184.1	2.141	5.626	14.564	1.142	40.826	3.66	1176.25	811.81	2.206

The qualitative content of the atmospheric release from the cleaning of the cutting line from paint-varnish coverings and vessel gas cutting is similar for designs of both the second- and the third-generation NS. The amount of the release varies according to the design [1.15, 1.16, 1.17, 1.18].

Average dust release for the cleaning from the paint-varnish covering is on the order of 1000 kg.

The average release for the gas cutting work is 2000 kg of the solid component and 2000 kg for the gas component.

The NS dismantling into blocks and large sections is performed in the dock chamber; the dismantling into open-hearth pieces is performed at the open site.

The calculation of the dispersion of the dangerous materials in the atmosphere was performed by the code “Ecologist” [1.18] according to the data of the FSUE “Zvezdochka”. It shows there is no MAC violation for the populated territories at the edge of the sanitary protection and dwelling zones.

It is worth noting that the FSUE “Zvezdochka” applies the mechanical technology of cutting the thin-sheet constructions with removable scissors “Caterpillar 375”, “La Bounty MSD 160”, automatic guillotine scissors Harris Waste management model BSY-30-2205A, which reduces the atmospheric release.

1.5.1.1. Liquid wastes

The sources of the liquid waste that contaminate the environment are the regular working liquids of the systems and equipment of the NS. The sources of the sewage water are the rinsing water with oil products arising from preparation of the tanks and equipment for heat dismantling [1.17].

Table 1.34 displays the data for the liquid waste and the sewage water.

Table 1.34 Characteristics of Liquid Wastes and Sewage Waters Resulting from NS Utilization

Name and danger class	Amount for the design, kg		
	Second-generation NS	**Second-generation NS**	**Third-generation NS**
1 Oil products (class 2): - diesel fuel - turbine oil - device oil - transformer oil - grease AMS-1 – grease PVK - grease «Litol» - compressor oil	3000 3400 1890 150 110 1500	3000 3200 1500 150 110	4200 4200 3800 40 510 6+6 3700
2 Hydraulic liquid PGV	4100	6950	11000
3 Acid electrolyte	1904	19835	17025
4 Alkaline electrolyte	300	300	500
5 Foam generator PO-1	50	65	964
6 Khladon $114B_2$	750	1743	1460
7 Khladon12	600	600	880
8 Inhibitor containing six-valence chrome	300	98700	-
9 Rinsing water with oil products	1300	13000	21000

According to the existing regulations, the wastes in Table 1.34 are dangerous wastes and should be utilized. The existing scheme of liquid waste and sewage water management at the enterprise includes collection, temporary storage, utilization, and neutralization.

According to the quarterly reports of the environmental object survey issued by the enterprise [1.11, 1.15], cases of the MAC violation with respect to the controlled parameters are absent. It does not mean the problem itself is absent. Nonstandard oil products of the utilized NS are burned in the boiler together with other spent oil products of the enterprise. Some part of the oil products is used for technological purposes.

The electrolytes are utilized at the local refining facilities together with other waste of the galvanic section.

The rinsing water is released into the canalization-refining facilities with the preliminary refining from the oil products in the oil traps.

The problematic wastes are the hydraulic liquid PGV, khladon $114B_2$, and the chrome-containing inhibitor. The PGV liquid and khladon $114B_2$ are accumulated in the storages.

There are no decisions to use khladon $114B_2$ for any purpose different from the technological necessities of the enterprise. Thermal neutralization results in the production of materials that are more toxic than khladon. Therefore, at the moment, the enterprise is not ready to utilize this way of neutralization. The optimal decision is to transport the khladon to the enterprises, which accept it for subsequent destruction.

According to its properties, the PGV liquid might be used as grease, for example, at the wood processing plants, or for agricultural equipment. Usually, such usage of the liquid results in soil pollution and dispersion of the PGV liquid by the ground water, which is forbidden by the ecological regulations. There is a technical decision for the thermal neutralization of the liquid. The practical implementation requires certain improvements to the existing designs of the boiler and the mazut (petroleum residue) equipment, the technology and methods of release control, and obtaining regulatory documents from the environmental protection bodies.

Chrome-containing water solutions of the inhibitor from the tanks of the biological shield with the concentration of the hexavalent chromium from 35 to 40 g/l are not processed during the NS utilization.

The methods of hexavalent chromium neutralization are well known. The enterprise uses reagent technology for neutralization of the chrome-containing sewage of the galvanic facility. This method can be used under certain conditions. It is necessary to dilute the inhibitor by water in the ratio approximately 1:100; to provide its supply to the entering unit portion by portion, allowing for the parameters and productivity of the refining facilities with respect to chrome; and to provide temporary storage of the inhibitor. The process requires a large amount of the reagent to transform $Cr^6 + Cr^3$ into sediment, and produces large amount of sediment.

There is a testing site near St. Petersburg (Krasnyi Bor settlement, “PEKOP” Ltd.), which accepts chrome-containing spent materials for neutralization by the electrocoagulation method. The method is more effective than the reagent one, but also requires temporary storage, reloading, and transportation.

In view of protecting the environment, it is necessary to find and develop other methods of neutralization, including separation of the pure potassium chromate for subsequent transfer to the chemical industry.

It is possible to transfer the inhibitor to the new NS under construction in the case when it is provided by the design project.

The total amount of the liquid waste and sewage water of various levels of ecological danger is approximately 121,600 kg per NS.

1.5.1.2. Solid waste

The solid wastes of the utilized NS are the main source of soil pollution.

The solid wastes are the mixed indivisible materials in the form of pieces and crumbs of various materials, fibers, tapes, threads with glue-like residues of the paint-varnish coverings, resins, compounds and sealing complexes, as well as and the whole plates, sheets, or mats [1.2, 1.10, 1.12].

Table 1.35 displays the list of the main solid waste according to the level of their ecological danger.

Table 1.35 List of the Main Solid Wastes

Name and danger class	**Amount in the design, kg**		
	Second-generation NS	**Second-generation NS**	**Third-generation NS**
1 Special gum coverings with the residual paint-varnish covering, compounds, glue, filler	> 400 000	>500 000	>1 000 000
2 Insulation:			
- packages FS-72-100 with residue of the glue IDS, tselalite, paint, coarse calico (class 3)	30348	35588	80708
- ATM mats with residues of the glue 88, threads, PM film (class 4)	2659	2636	4634
- PS-1 plates with epoxy filler (class 3)	9170	25000	68292
- layered plastic (class 3)	1300	830	2336
- crust, cork, glue 88, tselalite, IDS, polyamide and caprone texture (class 4)	6920	7750	9820
- KGL mastic, tselalite glue, asbestos, caprone texture (class 4)	748	2974	1784
- asbestos texture, tape, carton, filler (class 4)	3079	3590	4851
- silica texture, threads, cord, ink (class 4)	457	1723	2136
- kaolin cotton (class 4)	800	1872	4600
:			
3 Insulation of the electric cable with shell			

Name and danger class	Amount in the design, kg		
	Second-generation NS	Second-generation NS	Third-generation NS
- gum, polyethylene, polyvinylchloride	168000	170500	226000
- polyvinylchloride, polyethylene (class 4)	29600	29400	114000
4 Fiberglass with residue of the sealing (class 4)	1320	1399	6388
5 Asbosilit (class 4)	21600	22200	49310
6 Linoleum(class 4)	6300	6800	12561
7 Ceramics (class 4)	3100	2500	3741
8 Asbozurit (class 4)	427	635	1800
9 Luminescent mercury-containing lamps (class 1) (units)	1714	1500	5544
10 Ion-exchange resins (class 4)	1984	1644	3150
11 Slime of lead batteries (class 1)	600	600	600
12 Gum of various types and appointments	9738	15150	26657
13 Polymer materials of various types and appointments (class 4)	12650	19000	3936
14 Crumb, dust of the paint-varnish coverings with metal dust (class 3)	569	599	1000
15 Adsorbents (class 4)	279	736	6900 4600
16 Lumber (boards, bars, etc.), fiberglass, linen, cloth, duck, chamois, etc.(non-dangerous)	7631	8619	8561

The total amount of the solid waste of various levels of the ecological danger is on the order of 1,795,000 kg per NS, including 10,600 kg of class 1 danger, 121,000 kg of class 3 danger, and 1,663,400 kg of class 4 danger.

The amount of the nontoxic waste is approximately 18,000 kg.

At the moment, the facility for demercurization of the mercury-containing luminescent lamps is commissioned in Severodvinsk. It solves the problem of utilization of the class 1 waste of the utilized NS.

The class-3 wastes are still problematic. They include insulation materials FS-7-2-100 and PS-1-600, which release toxic phenol-formaldehyde and polystyrol, respectively. The reprocessing technology for these materials enabling their usage in other branches of industry and the neutralization technology are absent. The enterprises are forced to collect the waste of FS and PS and store them at temporary storages inside the enterprise site.

The class 4 wastes are permitted for evacuation to the industrial waste dump, which results in soil contamination. The significant parts of the waste are asbestos-containing materials, which is a carcinogenic component.

Reprocessing technology for the class 4 waste that would reduce their volume, exclude asbestos and resin release, and prevent dispersion of the polymer materials such as plastic compounds, linoleum, polyethylene, etc. that are broken down by the ultraviolet radiation, does not exist.

Part of the class 4 waste, such as gum plates, can be repeatedly used. They are stored at the temporary storage sites.

The amount of waste is reduced by implementation of the Triple Dynamics facilities for electric cable reprocessing.

Dust waste from coverings are problematic; dust from paint-varnish coverings contain lead compounds; dust from the insulation FS and PS; and dust from metal constructions and cable reprocessing, which are not gathered owing to absence of the equipment for simultaneous trimming and dust trapping. Dust is gathered together with the common trash, which results in the mixing of the wastes of different danger classes, which is forbidden by the regulation documents [1.17, 1.15].

Waste storing at the enterprise site is performed according to the permission and the accumulation limit approved by the environmental protection bodies.

The existing industrial waste site cannot manage the increasing volume of waste. New temporary sites are organized, and the unauthorized placement of the waste cannot be excluded.

Some wastes are flammable, which produces additional risk of fire in case of waste storing at the enterprise site and at the dump of the industrial waste.

1.5.1.3. Dust Content Characteristics

Dust content characteristics are considered based on the NS utilization in Severodvinsk. At the initial stage of the utilization process, the NS dismantling at the enterprise “Zvezdochka” was carried out in the slipway. The analysis of the results obtained by the labor safety department of the enterprise showed that the average levels of the dust content at virtually all sections exceeded the MAC by a factor of 1.3–6. Increased concentrations were found at the working places and at the neighboring sections, which indicates the possibility of the pollution transfer [1.12].

The data from the comparative analysis of the distribution of the primary measurements are displayed in the Table 1.36. It is clear from the table that the indicated dust content levels at the dismantling work sites are in the zone of the high concentrations. Different distributions are found in the neighboring sections (No. 4, 5), where the dust concentration is lower.

Table 1.36 Characteristics of the Dust Concentration in the Air when NS Dismantling in the Slipway (Data of the Labor Safety Department)

No.	Place of sampling	Technological operations	Number of samples in % to the total number		
			up to 1 MAC	1.1 - 5 MAC	>5 MAC
1	dock floor	gas cutting of the solid vessel	0	50	50
2	scaffold of the NS	gas cutting of the vessel and internal constructions	0	50	50
3	main bay (between two NS)	gas cutting of the vessel and internal constructions	0	0	100
4	7th floor	gas cutting of the vessel and internal constructions	70	30	0
5	crane track (near the large gate)	gas cutting of the vessel and internal constructions	28	72	0

The results of the investigations [1.12] of the dust content in the air during the process of dismantling the NS at the dock chamber of the FSUE “Zvezdochka” (Table 1.36) show that in this case virtually at all sampling points the average dust content exceeded the normal level. Such a situation occurred at the work places and at the neighboring sections. However, in this case, the wind direction is significant. For example, the sample taken at the section on the windward side featured a concentration lower than the MAC (No. 2 in Table 1.37). It is worth noting that the dust concentration in the air is determined to a certain extent by the volume and intensity of the technological operations, but this dependence is less pronounced in the dock chamber as compared to the slipway. For example, with increasing the number of cutters (No. 3, 4 in Table 1.37), the dust levels increase by virtually the factor of 1.5 (according to the previous investigations, the corresponding factor for the slipway was over 2.5 [1.2, 1.10]).

The most unfavorable sites with respect to hygienic conditions were the closed compartments (No. 6, 7 in Table 1.37) where the average dust concentration exceeded MAC by the factor of 20–27, and the maximum concentrations were still higher. At the same time, the dust content in the air did not satisfy the regulations for gas cutting in the open and partially closed compartments, though the dust concentration was significantly lower. The increased dust concentration is observed also 20–30 minutes upon completion of the gas cutting activity, which indicates insufficient efficiency of filter-ventilation installations.

Table 1.37 Characteristics of the Dust Concentration in the Air for the NS Dismantling in the Dock Chamber

No.	Sampling place	Performed operation	Meteorological conditions	Dust concentration	
				max	$X \pm Sx$
1	Platform of the dock chamber, upper point, 12-15 m from the workplace	Gas cutting of the internal constructions (12 cutters)	Leeward side, wind 3-5 m/s, $t^0=5^0C$	43.0	19.0 ± 12.6
2	Scaffold of the NS, at the level of the dock floor, 3-5 m from the work place	Gas cutting of the internal constructions (2 cutters)	Windward side, wind 1-2 m/s, $t^0=3^0C$	5.0	3.1±0.8
3	Dock floor, workplace of the cutter	Gas cutting of the floor (1 cutter)	Wind 1-2 m/s, $t^0=8^0C$	32.0	15.0 ± 4.8
4	Dock floor, workplace of the cutters	Gas cutting of the floor and bulkheads(4 cutters)	Wind 1-2 m/s, $t^0=3^0C$	36.0	22.4 ± 3.5
5	Partially opened compartment	Gas cutting of the	Wind 2-3 m/s,	56.0	19.0 ± 4.2

No.	Sampling place	Performed operation	Meteorological conditions	Dust concentration	
				max	X±Sx
	(cutter workplace)	internal constructions (1 cutter)	$t^0=4^0C$		
6	Between the solid and the light vessels (cutter workplace)	Gas cutting of the vessel (1 cutter)	Wind 3 m/s, $t^0=5^0C$	162.0	109.2 ± 70.6
7	On the vessel (cutter workplace)	Gas cutting of the vessel (1 cutter)	Wind 2-3 m/s, $t^0=7^0C$	204.0	80.0 ± 64.3
8	Opened compartment (cutter workplace)	Gas cutting of the equipment (3 cutters)	Wind 1-2 m/s, $t^0=7^0C$	22.0	17.0 ± 3.9
9	Opened compartment (cutter workplace)	Upon the work finish	Wind 1-2 m/s, $t^0=3^0C$	7.0	5.0 ± 1.9
MAC					4.0

The data in the Table 1.38 show that, similar to the work in the slipway, an increase in the work volume results in virtually doubling the number of samples exceeding MAC by the factor 5.1–10. For work in the closed compartments, most of the measurements lie within the interval 5.1–10 MAC (66.6%) and within the interval over 10 MAC (10%). Only at two sampling points (from nine investigated) are there measurements within the MAC, and in one case (No. 3 in Table 1.38) the concentration does not reach 20% of the MAC. 66 percent of samples taken after the work was completed exceed the MAC by the factor of 1.1–5, which confirms the conservation of the increased dust concentration after the finish of all operations [1.12].

Table 1.38. Comparative Characteristics of the Dust Content in the Air (MAC – 4.0 mg/m^3)

No.	Sampling place	Dust concentration distribution in %			
		Up to 1 MAC	1.1 - 5 MAC	5.1 - 10 MAC	> 10 MAC
1	Platform of the dock chamber, upper point, 12-15 m from the workplace	0	66.6	0	33.4
2	Scaffold of the NS, at the level of the dock floor, 3-5 m from the work place	60.0	40.0	0	0
3	Dock floor, workplace of the cutter	16.7	50.0	33.3	0
4	Dock floor, workplace of the cutters	0	40.0	60.0	0
5	Closed compartment, workplace of the cutter	0	57.2	21.4	21.4
6	Between the solid and the light vessels (cutter workplace)	0	0	0	100

No.	Sampling place	Dust concentration distribution in %			
		Up to 1 MAC	1.1 - 5 MAC	5.1 - 10 MAC	> 10 MAC
7	On the vessel (cutter workplace)	0	33.4	33.3	33.3
8	Open compartment (cutter workplace)	60.0	0	40.0	0
9	Open compartment (cutter workplace)	33.4	66.6	0	0

An analysis of the data obtained by FSUE NIIPMM, materials of the labor safety service of the "Zvezdochka" enterprise and the published data [1.17] shows that average levels of the dust concentration in the process of NS dismantling and construction operations are virtually the same. They exceed the MAC by the factor of 4.5–5.1 (see Table 1.39). This situation confirms that the working conditions are equally unfavorable for all comparable technological processes. It is worth noting that the increased levels of the dust concentration for the NS dismantling in the dock chamber occur in absence of the restrictions of the space volume (this work is performed in the open air).

It is also worth noting that in the case of the NS construction, the dust concentration levels are considered only within the period when certain operations are performed. Taking into account that the volume of gas cutting work reaches 60% of the working period (according to the timing data), while the volume of the welding work reaches only 25% of the work time [1.17], we arrive at the following conclusion. The average dust concentration levels and, correspondingly, the "dust load" for the involved personnel produced by the NS dismantling exceeds that of the construction work.

Table 1.39 Comparative Characteristics of the Dust Concentration Levels in the Air for NS Constructing and Dismantling, mg/m^3

No.	Workplace and the operation	Dust concentration ($X \pm Sx$)
1	Slipway, welding work (NS constructing)	21.2 ± 1.7
2	Slipway, gas cutting work (NS dismantling)	18.3 ± 3.1
3	Dock chamber, gas cutting work (NS dismantling)	18.0 ± 1.2

1.5.1.4. Aerosol releases

Analysis of the investigation results at the enterprise “Zvezdochka” performed for the NS dismantling in the slipway (table 1.40) shows that the average content of most of the determined components did not exceed the normative values. The only exceptions are manganese and lead; for these components, the number of samples exceeding the MAC was within 50–70%. MAC was exceeded with respect to manganese, nickel, and lead at the neighboring sections (No. 3 in Table 1.40), where, as already discussed, excess dust concentration also was observed. For other investigated places, the concentrations of all elements was very insignificant or below the detection threshold [1.12, 1.17].

Therefore, the characteristics of the qualitative content in general correspond to the characteristics of the dust level variation, and we can distinguish the dismantling work as the main source of the air pollution.

Table 1.40 Pollution of the Air during NS Dismantling in Slipway According to the Data of the Labor Safety Service, mg/m^3

No.	**Sampling places**	**Technological operations**	**Component content**						
			Dust	**CrO_3**	**Mn**	**Ni**	**Fe_2O_3**	**Pb**	**SiO_2**
1	Dock floor	gas cutting of the solid vessel sections	18.3 ± 3.1	0.006 ± 0.003	0.35 ± 0.05	0.15 ± 0.04	2.7 ± 0.4	0.04 ± 0.02	0.31 ± 0.05
2	Scaffold of the NS	gas cutting of the vessel and internal constructions	12.3 ± 9.0	0.004 ± 0.001	0.24 ± 0.03	0.015 ± 0.002	0.35 ± 0.01	0.03 ± 0.01	0.24 ± 0.12
3	Main bay (between two NS)	gas cutting of the vessel and internal constructions	24.2 ± 2.0	0.0120 ± 0.0006	0.44 ± 0.13	0.21 ± 0.06	2.54 ± 0.07	0.031 ± 0.004	0.61 ± 0.03
4	7th floor	gas cutting of the vessel and internal constructions	3.6 ± 1.7	not found	not found	not found	0.24 ± 0.02	0.045 ± 0.001	0.012 ± 0.002
5	Crane tracks (near the large gate)	gas cutting of the vessel and internal constructions	5.2 ± 0.5	not found	0.027 ± 0.04	not found	0.29 ± 0.04	0.003 ± 0.001	0.09 ± 0.02
MAC			4.0	0.01	0.2	0.05		0.01	1.0

The investigation results [1.12, 1.17] show that the dust released into the air during the NS dismantling in the dock chamber also contains a complex of elements (Table 1.41).

As it follows from the Table, the average levels of concentration of 66.6% of all determined metals at all investigated places does not exceed the normative values. The remaining 33.4% are manganese, nickel, lead, zinc, and tin. High concentrations (up to 13–60 MAC) of lead occurred at the 2nd, 3rd, and 5th sampling points. This is explained by the fact that these workplaces performed gas cutting of the constructions that are covered by red lead or contain lead as the main component (electric cables); it is reflected in the hygienic characteristics of the individual workplaces [1.12].

Increased average concentrations, up to 2–10 MAC, were found for nickel; with increasing work intensity, its concentration increased by the factor of 5 (No. 3, 4 in Table 1.41). At four workplaces (No. 3, 5, 6, 10 in Table 1.41), the increased concentrations of manganese were observed, up to 1.5–3 MAC. The maximum concentrations of these elements as well as of zinc were recorded either under conditions of increased intensity of the gas cutting work, or where the work is carried out in closed or partially closed compartments. It is important to emphasize that in this case, we estimated the average concentrations of the elements observed when the specified operations were performed. Taking into account that the maximum individual concentrations of the aerosols usually exceed the average values by several times (or even several dozens), the hygienic situation at the NS dismantling workplaces should be considered as unfavorable with respect to the concentration of toxic metals.

It is interesting to perform a comparative analysis of the air pollution by metals for dismantling and construction of the NS [1.17]. The construction study includes relatively similar work sections.

Table 1.41 Metal Concentration in the Air at the NS Dismantling, mg/m^3 ($X \pm S_x$)

No.	***Sampling place***	***Technological operation***	***Mo***	***Cr***	***Mn***	***Ni***	***Pb***	***V***
1	Platform of the dock chamber, upper point, 12-15 m from the workplace	Gas cutting of the internal constructions (12 cutters)	6.1×10^{-3}	$(3.6 \pm 0.8) \times 10^{-3}$	$(2.7 \pm 0.4) \times 10^{-2}$	$(5.0 \pm 0.7) \times 10^{-3}$	$(1.2 \pm 0.2) \times 10^{-2}$	$(3.2 \pm 0.7) \times 10^{-4}$
2	Scaffold of the NS, at the level of the dock floor, 3-5 m from the work place	Gas cutting of the internal constructions (2 cutters)	$5.0 \pm 5 \times 10^{-3}$	$(8.3 \pm 2.3) \times 10^{-3}$	0.17 ± 0.05	$(1.1 \pm 0.4) \times 10^{-2}$	0.13 ± 0.04	$(2.0 \pm 0.2) \times 10^{-4}$
3	Dock floor (cutter workplace)	Gas cutting of the floor elements (1 cutter)	$(1.6 \pm 0.3) \times 10^{-2}$	$(7.5 \pm 1.4) \times 10^{-2}$	0.8 ± 0.2	0.10 ± 0.02	0.6 ± 0.2	$(2.0 \pm 0.6) \times 10^{-3}$
4	Dock floor (cutter workplaces)	Gas cutting of the floor and the bulkhead elements (4 cutters)	$(2.5 \pm 0.4) \times 10^{-2}$	0.11 ± 0.05	0.26 ± 0.06	0.5 ± 0.2	$(8.9 \pm 2.6) \times 10^{-2}$	$(2.5 \pm 1.0) \times 10^{-3}$
5	Partially closed compartment (cutter workplace)	Gas cutting of the internal constructions (1 cutter)	1.9×10^{-2}	$(5.0 \pm 0.8) \times 10^{-2}$	0.5 ± 0.1	$(9.6 \pm 2.7) \times 10^{-2}$	0.30 ± 0.06	$(6.9 \pm 1.0) \times 10^{-4}$
6	Between the solid and the light vessels (cutter workplace)	Gas cutting of the vessel (1 cutter)	$(5.92 \pm 3.3) \times 10^{-2}$	0.18 ± 0.06	1.5 ± 0.5	0.15 ± 0.05	$(5.2 \pm 2.2) \times 10^{-2}$	$(3.1 \pm 0.9) \times 10^{-3}$
7	On the vessel (cutter workplace)	Gas cutting of the vessel (1 cutter)	-	$(3.6 \pm 1.3) \times 10^{-2}$	$(6.3 \pm 1.5) \times 10^{-2}$	0.14 ± 0.01	$(9.7 \pm 4.4) \times 10^{-2}$	$(1.5 \pm 0.5) \times 10^{-4}$
8	Open compartment (cutter workplaces)	Gas cutting of the equipment (3 cutters)	$(5.4 \pm 1.5) \times 10^{-3}$	$(1.3 \pm 0.3) \times 10^{-2}$	$(5.3 \pm 1.6) \times 10^{-2}$	$(3.5 \pm 1.1) \times 10^{-2}$	$(3.6 \pm 1.3) \times 10^{-2}$	$(8.1 \pm 1.1) \times 10^{-4}$
9	Open compartment (cutter workplaces)	After the work finish	$(1.8 \pm 0.1) \times 10^{-3}$	$(5.1 \pm 1.7) \times 10^{-3}$	$(1.2 \pm 0.5) \times 10^{-2}$	$(1.2 \pm 0.6) \times 10^{-2}$	$(3.6 \pm 1.5) \times 10^{-2}$	$(2.7 \pm 0.6) \times 10^{-4}$
10	Open compartment (cutter workplaces)	Inflammation of the facing elements (no operations)	-	$(2.8 \pm 1.5) \times 10^{-2}$	1.0 ± 0.6	$(5.4 \pm 2.9) \times 10^{-2}$	$(3.3 \pm 2.2) \times 10^{-2}$	$(4.6 \pm 1.8) \times 10^{-4}$
11	Open compartment	Cordage operations	$(3.2 \pm 0.5) \times 10^{-3}$	$(8.4 \pm 2.0) \times 10^{-3}$	$(3.8 \pm 1.3) \times 10^{-2}$	$(1.6 \pm 0.3) \times 10^{-2}$	$(8.4 \pm 2.2) \times 10^{-2}$	$(7.6 \pm 2.0) \times 10^{-4}$
12		MAC	0.5	1.0	0.3	0.005	0.01	0.5
1	Platform of the dock chamber, upper point, 12-15 m from the workplace	Gas cutting of the internal constructions (12 cutters)	$(1.2 \pm 0.6) \times 10^{-3}$	$(3.3 \pm 0.4) \times 10^{-3}$	$(5.4 \pm 0.4) \times 10^{-4}$	$(2.2 \pm 0.2) \times 10^{-2}$	$(3.1 \pm 0.8) \times 10^{-3}$	-

No.	***Sampling place***	***Technological operation***	***Mo***	***Cr***	***Mn***	***Ni***	***Pb***	***V***
2	Scaffold of the NS, at the level of the dock floor, 3-5 m from the work place	Gas cutting of the internal constructions (2 cutters)	$(1.4 \pm 0.2) \times 10^{-3}$	$(3.7 \pm 1.0) \times 10^{-2}$	$(1.6 \pm 0.3) \times 10^{-2}$	0.123 ± 0.03	$(4.9 \pm 1.2) \times 10^{-3}$	-
3	Dock floor (cutter workplace)	Gas cutting of the floor elements (1 cutter)	$(6.0 \pm 3.5) \times 10^{-2}$	$(9.4 \pm 1.7) \times 10^{-2}$	$(1.1 \pm 0.4) \times 10^{-2}$	0.4 ± 0.1	$(7.5 \pm 3.4) \times 10^{-2}$	-
4	Dock floor (cutter workplaces)	Gas cutting of the floor and the bulkhead elements (4 cutters)	$(8.8 \pm 2.4) \times 10^{-3}$	$(5.9 \pm 1.5) \times 10^{-2}$	-	0.13 ± 0.06	$(3.1 \pm 1.1) \times 10^{-2}$	$(4.1 \pm 0.7) \times 10^{-2}$
5	Partially closed compartment (cutter workplace)	Gas cutting of the internal constructions (1 cutter)	$(1.5 \pm 0.2) \times 10^{-2}$	$(8.7 \pm 1.0) \times 10^{-2}$	$(1.8 \pm 0.6) \times 10^{-2}$	0.25 ± 0.05	$(4.8 \pm 1.2) \times 10^{-2}$	-
6	Between the solid and the light vessels (cutter workplace)	Gas cutting of the vessel (1 cutter)	$(4.4 \pm 1.0) \times 10^{-3}$	$(8.0 \pm 1.2) \times 10^{-2}$	$(4.5 \pm 2.0) \times 10^{-2}$	1.8 ± 0.3	$(8.6 \pm 2.1) \times 10^{-3}$	-
7	On the vessel (cutter workplace)	Gas cutting of the vessel (1 cutter)	3.6×10^{-3}	$(3.7 \pm 0.3) \times 10^{-2}$	3.2×10^{-3}	$(2.2 \pm 0.7) \times 10^{-2}$	$(1.5 \pm 0.1) \times 10^{-2}$	-
8	Open compartment (cutter workplaces)	Gas cutting of the equipment (3 cutters)	$(9.4 \pm 2.2) \times 10^{-3}$	$(2.8 \pm 0.4) \times 10^{-2}$	$(3.8 \pm 0.6) \times 10^{-4}$	$(1.4 \pm 0.1) \times 10^{-2}$	$(8.2 \pm 1.7) \times 10^{-3}$	-
9	Open compartment (cutter workplaces)	After the work finish	$(3.1 \pm 1.0) \times 10^{-3}$	$(9.3 \pm 3.9) \times 10^{-3}$	$(1.1 \pm 0.5) \times 10^{-2}$	$(6.8 \pm 4.3) \times 10^{-2}$	$(7.1 \pm 1.9) \times 10^{-3}$	-
10	Open compartment (cutter workplaces)	Inflammation of the facing elements (no operations)	$(2.1 \pm 1.0) \times 10^{-3}$	$(8.6 \pm 4.9) \times 10^{-2}$	4.6×10^{-2}	0.2 ± 0.1	$(2.5 \pm 1.9) \times 10^{-2}$	-
11	Open compartment	Cordage operations	$(4.3 \pm 1.6) \times 10^{-3}$	$(3.2 \pm 1.3) \times 10^{-2}$	$(2.6 \pm 1.0) \times 10^{-3}$	$(5.7 \pm 2.2) \times 10^{-2}$	$(5.7 \pm 1.2) \times 10^{-3}$	-
12		MAC	0.05	1.0	0.1	0.5	10.0	0.5

We note that the NS dismantling was performed in the dock chamber, while construction was performed in the slipway, with all specific features of the formation of the air pollution.

The data in Table 1.42 show that the concentration levels of manganese and chrome during the welding operations (NS construction) at the open sites is statistically higher ($p<0.05$) than for the dismantling operations. The similar tendency is true for the nickel concentration. It is important to note that, during the welding operations, the aerosols formed by the electrode coating materials are released into the air of the work compartments. Manganese, chrome, and nickel are contained in large amounts in the electrodes.

The same operations performed in the closed or partially closed compartments feature the manganese concentration at the same level; the concentrations of nickel and chrome did not show any statistically significant difference ($p>0.05$). This example confirms the revealed specific features of the formation of the air pollution during the NS dismantling in the dock chamber, which are the consequences of the restricted space volume.

Table 1.42 Comparative Characteristic of the Air Pollution by Metals when NS Dismantling and Constructing ($X \pm S_x$)

No	Technological operations, sampling places		Metal concentration, mg/m^3		
			Mn	Cr	Ni
1	NS construction	Open space	1.4 ± 0.3	0.26 ± 0.03	0.16 ± 0.06
		Closed, partially closed compartments	1.2 ± 0.3	0.5 ± 0.2	0.21 ± 0.06
2	NS dismantling	Open space	0.36 ± 0.02	0.05 ± 0.01	0.14 ± 0.07
		Closed, partially closed compartments	1.0 ± 0.5	0.11 ± 0.07	0.12 ± 0.03

In line with sampling and measuring the solid component of the released aerosols, the authors of the investigation also measured the concentration levels of certain organic compounds (Table 1.43) [1.12, 1.17].

Table 1.43. Concentration of the Organic Components in the Air of the Operation Zone, mg/m^3

Sampling places	Component concentration		
	Dibutyl phthalate	**Epylchlorhydrite**	**Toluene**
Dock floor	1.97	2.54	-
MAC	0.5	1.0	50.0

It is clear from the Table that the air of the operation zone contains organic materials with the concentrations exceeding the MAC by the factor of 2.5–4. In this case, it is important to notice the presence of the additional harmful factors and the possible combined effect of the organic and inorganic compounds on the personnel. The problem is not yet studied in detail and requires additional consideration.

In conclusion, it is necessary to emphasize that, allowing for high levels of dust concentrations during the gas cutting operations and, simultaneously, relatively low (with certain exceptions) concentration levels of detectable metals, one can consider the following. The main contribution to the air dust content comes from the products of thermal degradation of the raw materials that make up the content of the utilized constructions and, evidently, iron oxides [1.12, 1.17].

1.5.2. Danger for the personnel

The calculation shows that the approximate values of the dust "loads" reach 107.7 mg per shift for the operations in the open air and 1224.9 mg per shift for the operation in the closed compartments [1.2]. Therefore, the obtained results show that the gas cutters working in the closed or other not easily accessible compartments can receive a dust load exceeding that for the operations in the open air by a factor of 11.3. It is necessary to emphasize that in this case, we considered the most unfavorable period of the gas-cutting works, when the volume of the operations in the closed compartments was equal to that in the open air. The dust load for the dismantling operations in the closed compartments was higher by the factor of 1.8 compared to the construction operations, but at the same time lower by the factor 1.7 than for the similar operations in the open air.

Along with low dangerous and medium dangerous materials (danger classes 3 and 4), certain materials are treated as highly dangerous or extremely dangerous substances (danger classes 1 and 2). This rating depends on their physical and chemical properties, the aggregate state, volatility, ability to participate in chemical reactions, and the direction of biological effects with consideration for the possibility of their combined action.

The effects of the components on the human organism are divided into:

- toxic (vapors of metals, khladons, acids, alkalines, paints, etc.);
- carcinogenic (asbestos, nickel oxides, etc.);
- fibrogenic (asbestos, concrete, fiberglass, silicon dioxide, etc.);
- allergenic (formaldehyde, epylchlorhydrite, chrome and nickel oxides etc.).

All of them affect skin, mucosa, and respiratory paths.

It is known from the publications that heavy metals released during the operations related to NS utilization are the most important elements, which determine so-called “metal press” on the biosphere. The leading components with respect to the effect on the human being, among other pollutants of the environment, are the ecotoxicants that enter the organism through the respiratory path. In this case, their intake to the internal media of the organism is more intensive that for the other intake paths.

The most important metals released in the course of the NS dismantling are titanium, zinc, copper, lead, nickel, manganese, and chrome. Owing to these materials, the concentration of the individual toxicants in the operation zone sometimes exceeds the permissible level.

An estimate of the human body toxicant intake can be obtained from the data on metal sedimentation by the means of the personnel individual protection (respirators). Taking into account that the efficiency of these means is approximately 75% per shift, we can assume that the inhaled amount of the toxicants reaches 30% of the sedimented amount.

The most significant accumulation of metals entered the human body is known to occur in the bones. However, the bones cannot be tested in vivo. Therefore, it is possible to analyze hairs, which are also known to accumulate metals and are the most accessible material for determination of the effect of harmful chemical materials on the human organism. Therefore, the results of such investigations can be considered as a criterion to estimate working conditions of the personnel in the shipbuilding industry.

The main source of metals in the air of the production compartments at the ship-repairing plants is the solid aerosol phase of the production dust and the welding aerosol (condensation aerosol). All metals released in the gas-cutting processes of the NS utilization are highly toxic. For example, welding aerosols produced in the burnup of the chrome-containing electrodes are very toxic. The aggressivity of the aerosol-containing compounds of hexavalent chromium (VI) and trivalent chromium (III) results in the subtrophic mutation and ulceration of the respiratory mucosa, perforation of the cartilaginous part of the nasal septum, and disease of the respiratory organs, up to development of pneumosclerosis [1.19, 1.20]. Changes in tooth color, appearance of the gum border, ulcerous condition, toxic hepatitis, and nephritic diseases are also observed [1.20]. Chromium poisoning results in the changes of the ferment activity, violation of the protein exchange; the patients with developing chromium poisoning feature phase changes in the cholinergic blood activity [1.22, 1.23]. Protracted contact with chrome and manganese leads to the decrease in the protective and adaptation capabilities of the organism, development of respiratory diseases, and increases the risk of oncological diseases [1.23–1.26].

Copper is the source of health risks from the welding process. Chronic intoxication by copper and its compounds leads to functional violations of the nervous system, liver, and kidneys; ulceration and perforation of the nasal septum; cerebral angioneurosis; leukocyte deficiency; and diseases of the alimentary canal [1.27, 1.28]. There is clear correlation of the copper content in the workers' hairs with the stage and character of work.

The risk of acute inhalation intoxication is also related to the aerosols of zinc and its oxide and chloride. Zinc has cumulative toxic effects even at small concentrations in the air [1.29]. Acute intoxications, with typical picture of the pouring fever observed for arc welding and gas cutting of the zinc-containing constructions, are described in the publications. The workers of the galvanic sections, solderers, painters, and galvanizers have zinc contents in hairs up to 27.2 mg%, 25.5 mg%, 22.9 mg%, and 30.04 mg%, respectively (7.76 mg% for the control group).

The common feature of all nickel-containing aerosols is the high dispersion level of the dust suspended in the air (particle size below 1 μm) and large depth of the respiratory path penetration. The effect of the sulfides, oxides, and metal nickel can result in the pathology of the respiratory path in the form of the chronic bronchitis or the pneumoconiosis.

The effect of titanium compounds on the human organism also features pathology of the upper and lower parts of the respiratory path.

Inhalation of lead compounds result in pathology of the nervous system, alimentary canal, and cardiovascular system. Dermatitis, allergy, respiratory and blood system diseases are usually observed. One of the most important paths of the lead intake to the human body is the pollution of the air in the working zone and the atmosphere by the lead compounds. Inhibition of the lead aerosols in lungs is determined by the size of the particles, which varies between 27 and 62%.

Large amounts of lead are accumulated in human hairs. The average lead concentration in the hairs of the rural population can increase up to 20 μg/g; that of the urban population up to 60μg/g. At the same time, the lead mill workers have lead concentration in hairs from 95 to 250 μg/g. There is a correlation between lead concentration in hairs and blood. The lead concentration 7 μg/g in hairs corresponds to the concentration 600 μg/L in blood. There is also a correlation between lead concentration in hairs and the clinical picture of the intoxication. The lead excretion with urine strongly depends on its concentration in the air of the work zone [1.30, 1.31].

1.6. General Estimation of the Radiation and Ecological Safety of Units, Installations and Technologies Used when Utilizing Nuclear Submarines of the Arctic Navy

1.6.1. Review of the Process of RW Handling

On special-purpose vessels, within coastal enterprises of the Navy, and shipbuilding and ship-repair yards of the Russian Shipbuilding Agency and the Navy that are located in the Northwest region, the following RW amounts are accumulated and stored [1.5]:

- over 3400 packages with SF of PWR and six spent extractable parts of liquid metal coolant reactors;
- about 8000 m^3 of LRW of the integral activity of 256 Ci (including 300 m^3 of high-active LRW); and
- over 12100 m^3 of SRW of the integral activity over 5000 Ci (including 876 m^3 of high-level SRW).

The design life of principal CSE installations in Andreeva bay and Gremikha settlement is expended, and as a consequence, part of these installations are in an emergency state.

Within CSE of Andreeva Bay and Gremikha settlement there are areas of local contamination of the ground due to washing of radioactive substances out of damaged SF repositories.

When considering nuclear maintenance support vessels (floating servicing enterprises, technical tankers of LRW storage, etc.), the design life of most NMSV is also up; these vessels are unserviceable and are to be utilized.

At present, SF unloading is carried out by two FSE, design 2020 (in the water areas of Murmansk and Severodvinsk). Together, these FSE are able to unload SF out of reactors of up to six nuclear submarines per year. At this rate, about 12 years is required to unload SF out of all decommissioned NS of the Navy. In the immediate future, construction of a new complex of coastal installations to unload SF out of nuclear submarines will be completed.

Two special-purpose trains transport SF in TUK-108 transportation casks for reprocessing at "Mayak" PA.

Further increase of the pace to remove SF of vessel PRF is limited by productive capacities of “Mayak” PA. In actual operation, the RT-1 spent fuel reprocessing line at “Mayak” PA is able to reprocess up to 10 ton of SF from vessel PRF per year; therefore, with the application of present-day technologies only 12 trains loaded with SF at the most can be removed annually [5].

The state of special-purpose repositories to store SRW temporarily as well as of temporary sites of SRW storage does not comply with the safety regulations now in force. They represent open-air structures exposed to atmospheric precipitation, without any drainage system; furthermore, currently they are 100% full. Radioactive substances contaminate the soil around these storage-areas. The integral activity of accumulated SRW exceeds 5000 Ci. Considering increasing efforts to utilize NS, the amount of SRW can at least double.

At CSE of Andreeva Bay, the construction of a new SRW repository (installation 67) is completed. However, the repository will be put into operation only following an examination by Minatom of Russia for compliance with standard acts now in force.

In the Northwest region of Russia, no SRW-conditioning capacities are currently available. Storage conditions of all SRW represent an environmental hazard and do not comply with actual requirements.

To store SRW, there are installations at some enterprises of Severodvinsk-town:

- The 1840 m^3 of capacity at SRW repository in Mironova Mountain (“Sevmash PA”) is 100% full. Here, SRW has been stored since 1964. The actual technical state of the repository is considered as unsatisfactory. At present, preproject investigations are being carried out to develop measures for the repository closure (designer – State Special-Purpose Design Institute - SSPDI);
- The site of SRW temporary storage of FSUE "Sevmash PA” is 2475 m^2 in area. At present, the site is almost empty since SRW created in the process of NS handling are loaded into cutout reactor compartments and then transferred to the Navy for long-term storage. However, no sufficient feasibility study was performed for use of such technology;
- Storage of solid and dry radioactive wastes in SMBE "Zvezdochka", 1530 m^3 in capacity, is 55% full. The storage technical state does not comply with present-day requirements of ensuring the radiation safety;

- The open-air site of SRW temporary storage within SMBE "Zvezdochka" is 6685 m^2 in area. The site is designed to store SRW temporarily in containers as well as large-size equipment. Another site of SRW temporary storage, 3000 m^3 in capacity, is under construction.

The integral SRW amount within enterprises of Severodvinsk-town exceeds 2000 m^3 with the total activity of 1100 Ci. Increasing the pace of RW accumulation obviously demonstrates the necessity of constructing new SRW repositories.

1.6.2. Characteristics of Accumulated Radioactive Wastes and RW under Creation

Within sites and installations of the Navy and Russian Shipbuilding Agency, about 4400 m^3 of process LRW and 900 m^3 of SRW are accumulated. About 70% of the accumulated and currently created LRW are stored within the Kola Peninsula and 30% in the area of Severodvinsk-town. Eighty percent of SRW are accumulated and created in sites and installations of the Kola Peninsula and 20% in those of Severodvinsk-town area.

Low-active waters of special laundries and decontamination centers constitute a particular LRW category. Their amount exceeds that of process LRW by about 25 times, whereas only 10 to 20% of these waters have specific activities over $1 \cdot 10^{-7}$ Ci/L.

Waters of special laundries and decontamination centers are created at all installations under consideration, and their overall volume makes up 112,000 m^3/year. Most of this quantity is created by SMBE «Zvezdochka» (up to 100,000 m^3), Ship-Repair Yard "Nerpa" (up to 3000 m^3), CSE-928/111 (up to 2000 m^3) and FSUE “Sevmash PA” (up to 2000 m^3).

At Service and Repair Enterprise «Atomflot», up to 1200 m^3 of process LRW and about 300 m^3 of waters of special laundries and decontamination centers are created annually in the course of nuclear vessel reloading and repair operations. «Atomflot» is also responsible for about 250 m^3/year of SRW. At the present time, 500 m^3 of process LRW and 760 m^3 of SRW (including those created in the process of combustible waste burning) are accumulated within SRE “Atomflot”.

In keeping with international agreements and obligations accepted by the Russian Federation, 130 nuclear submarines of the first, second and third generation and nuclear maintenance support vessels (floating servicing enterprises and technical pouring tankers) are to be decommissioned from the Navy prior to 2020 [1.1, 1.2].

By now, nine NS of the first- and the second generation are utilized. For lack of properly equipped TSS and long-term storage stations for reactor compartments, NS dismantling operations are performed as follows: cutting out three-compartment units (a reactor compartment and two adjacent compartments) or cutting out the reactor compartment and its joining with floating tanks. Cut-out reactor compartments and three-compartment units of dismantled NS are kept in "afloat" conditions within ship-repair yards (which perform NS dismantling and utilization) and in temporary storage stations (TSS «Saida»).

1.6.3. Characteristics and the Current State of Special-purpose Transport Facilities

To accept, store and transport LRW, various types of floating servicing vessels (technical pouring tankers, floating servicing enterprises, floating tanks, etc.) and coastal storage structures are used in the Navy. They are of different storage capacity and able to accept wastes of the activity from $1 \cdot 10^{-2}$ Ci/l to $1 \cdot 10^{-5}$ Ci/L.

The overall number of floating servicing vessels still in operation is 28, with the integral LRW volume of 6800 m^3. Most of such vessels used by the Navy are now out of date. As a result, actually only some of the TPTs and the "Amur" special-purpose tanker can be used as transport facilities. The "Amur"- tanker is a multi-purpose design, including: - LRW acceptance and treatment and - acceptance and transportation of spent fuel assemblies, LRW and SRW.

To carry out handling of radioactive wastes produced by the civil atomic fleet, floating servicing enterprises «Imandra», «Serebrianka», «Lotta» and "Lepse" are used, which belong to "Atomflot" Repair and Technical Enterprise. These vessels are only used to accept and store LRW and SFA [1.94, 1.126].

At present, FSE “Lepse” is the most dangerous vessel since she stores 640 damaged SFA, which cannot be reprocessed at “Mayak” PA because of technical reasons. The vessel was built in 1934. After reconstruction in 1961, “Lepse” has been used as a floating servicing enterprise of the Atomic Fleet.

To solve the problem of FSE “Lepse” utilization, an international-status project has been developed and a “Consulting committee of “Lepse”- project” has been created. By now, EC "MEPCO"-Association of Scandinavian countries, France, Norway and the Netherlands have expressed their desire to participate in the project.

Milestones and estimated costs (million USD) to carry out the project are listed below:

- the integral project development and environmental impact assessment - 0.5;
- constructing special technological equipment and perfecting techniques for damaged SFA unloading – 1.5;
- damaged SFA unloading – 3.0;
- making metal-concrete containers to store damaged SFA- 7.5; and
- constructing a site to store metal-concrete containers or reconstructing the existing building № 5 – 4.2.

FSE «Imandra» has five tanks, 300 m3 integral volume, whereas FSE «Serebrianka» possesses eight tanks, 1000 m^3 of the overall volume. These FSE accept and store separately LRW resulting from decontaminating and drainage operations. Low-salted LRW (created when cooling SFA prior to performing handling operations) are collected at FSE «Lotta». These wastes are then transferred to storage in tanks of FSE «Imandra» or «Serebrianka».

1.6.4. Generalized Conclusions for Part 1

Based on the above analysis related to the radioecological state of units and installations involved in the process of nuclear submarine handling after the decommissioning in the Northwest region of Russia, the following generalized conclusions can be drawn:

1. As a whole, under normal (standard) conditions of nuclear submarine long-term waterborne storage after the decommissioning and when performing dismantling operations, issues of ensuring nuclear and radiation safety are solved in accordance with the established procedures. Until the present time, no case of appreciable worsening of the radioecological

situation within the region concerned has occurred. However, the reached safety level cannot be considered as sufficient and requiring no improvement because of the following reasons:

- increasing pace of nuclear submarine dismantling;
- an imbalance between volumes of spent fuel accumulated in the region and those transported away; and
- increasing amounts of radioactive wastes concentrated in areas of both nuclear submarine waterborne storage and dismantling.

2. At the present time, spent fuel repositories (storing SF in both coastal and afloat conditions) have the greatest potential hazard. Their integral radiation potential exceeds 240 million Ci, including $25 \bullet 10^6$ Ci in Arkhangelsk region and over $220 \bullet 10^6$ Ci in Murmansk region. Liquid and solid radioactive wastes resulting from both nuclear vessel operation and dismantling after the decommissioning also possess an important radiation potential. Their amounts can be characterized as follows:

   <u>SRW:</u> Altogether over 9180 m^3 of the integral activity about $1.6 \bullet 10^3$ Ci.

   <u>LRW:</u> Altogether over 3000 m^3 of the integral activity about 45 Ci.

3. At present, especially after the events of September 11, 2001, the risk of terrorist attacks must not be ruled out. In a case of severe damages from the outside, uncertainties could appear in the behavior of nuclear reactors and spent fuel repositories. Under conditions of severe accidents, redistribution of fuel and changes in its configuration would be possible that could lead to different incidents including nuclear ones. Until now, no comprehensive investigation of such phenomena has been performed. To ensure nuclear safety, issues related to SF accelerated unloading from nuclear vessels and SF removal from repositories for reprocessing must be solved in a drastic fashion.
4. The radiation potential of SF still stored within 50 nuclear submarines makes up 112 million Ci, i.e., about 50% of the overall amount of SF in the region under consideration. Under present-day conditions (lack of personnel, unsatisfactory material support, modest volumes of preventive repair work, total lack of dock inspections and repair of the decommissioned nuclear submarines, transfer of a part of nuclear submarines to civil crews and other circumstances) it is not improbable that a part of NS under consideration will be sunk for the purpose of safety. Such actions have already taken place in the Pacific Navy. If the primary circuit of the NS power reactor facility remains pressurized, the radiation consequences of such an incident would remain insignificant. But the consequences could be more dangerous in a case of sinking a vessel with a damaged reactor or in the process of the reloading reactor. All these concerns also apply to NMS vessels storing and transporting nuclear fuel. The potential consequences of such emergencies necessitate a comprehensive analysis and development of measures to prevent their initiation and, in case of need, to provide for their localization.
5. The work related to nuclear submarine handling after the decommissioning results in important releases of gas, aerosols and dust into the atmosphere. The existing equipment is unable to protect the personnel; moreover, it gives no way to avoid the pollution by non-radioactive substances of the air, soil and water area around the concerned enterprises.

Despite the fact that concentrations of individual pollutants do not exceed admissible limits, gradual increase of their concentrations is observed in the majority of cases. This circumstance requires additional actions to improve the ecological monitoring within and around enterprises involved in handling of nuclear submarines, spent fuel, and liquid and solid radioactive wastes.

6. A comparative analysis of different NS utilization techniques used in the enterprises under consideration obviously demonstrates the following. To cut out NS hulls, a far short of optimum, rather dangerous and expensive technology of gas-plasma metal cutting has been employed. To cut one ton of steel 20 mm in thick with the observance of MAC_{co} = of 20 mg/m^3 in the course of gas-cutting operations, 35 million m^3 of air is polluted by different hazardous substances (a half-sphere of R=5500 m represents its equivalent).

Clinical examinations confirm that such a technology constitutes a potential threat to both the health of working personnel and the environment.

Both scientists and engineers support more and more the idea of further search for new technologies of cutting out hulls of nuclear vessels, continuation of comprehensive studying and estimating NS utilization consequences, as well as the issues of ecological rehabilitation of nuclear-powered units and installations of their supporting infrastructure.

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2. Analysis of the Ecological Situation of Territories (Water Areas) in the Vicinity of Units & Installations of NS Handling after the Decommissioning

2.1. Radioecological Situation in Waterborne Storage Areas of NS and Reactor Units to Be Utilized

In addition to economic and technological issues, the decommissioning of NS, surface vessels with PRF, and NMSV represents a serious radioecological and medical problem.

Out-of-service nuclear vessels are a powerful source of ionizing radiation and radioactive contamination. From the hygienic point of view, they contain many hazardous radionuclides, i.e., ^{55}Fe, ^{59}Fe, ^{54}Mn, ^{60}Co, ^{134}Cs, ^{137}Cs, ^{90}Sr, ^{63}Ni, ^{94}Nb and others with half-lives varying from several years up to tens of thousands of years.

There is a potential hazard of radioactive contamination of the environment as well as of radiation exposure of both the personnel and population due to the location of NS within waterborne storage areas (WSA) in relatively close vicinity to inhabitable territories. This imparts to the problem a particular social meaning and requires the application of specific technologies that will be able to minimize potential negative effects.

At the same time, the issues of ensuring the radiation safety at different NS decommissioning stages, the pathways of environmental contamination, the values and the structure of exposure doses for both the personnel and population are poorly studied up to now. Neither hygienic recommendations for personnel and the population protection nor appropriate environmental protection measures are available.

Among nuclear vessels to be decommissioned, the following four types of nuclear-powered units and installations should be distinguished depending on their specific radiation situation, the presence or absence of the core, and the dismantling techniques used (Table 2.1):

Non-damaged NS stored afloat with the core;
Non-damaged NS stored afloat without the core;
Afloat stored NS with damaged PRF; and

NS stored afloat temporarily after partial dismantling (including three-compartment floating units).

Table 2.1 Stages of the Decommissioning and Types of Nuclear Vessels to Be Utilized

Non-damaged NS		NS after a radiation accident
Ist stage – waterborne storage		
Ist type Afloat stored NS with the core	**IInd type** Afloat stored NS without the core	**IIIrd type** Afloat stored NS with damaged PRF
IInd stage – preparing stage and temporary waterborne storage		
IV-th type Multi-compartment or three-compartment units of temporary storage		

In NS of both afloat storage and temporary storage (types I, II and IV) the main sources of ionizing radiation are the induced activity and the surface contamination of structural and protective materials of both PRF and the vessel hull, as well as the core and coolant, if not removed.

In afloat stored NS with damaged PRF (the III-rd type), the radiation situation is mainly determined by the level of surface contamination of NS equipment and the hull by radioactive substances created as the result of the core collapse as well as construction materials inside the reactor.

As a rule, the radiation situation in compartments and on the hull of non-damaged NS is similar to that on vessels in operation when their reactors are shutdown. By contrast, the radiation situation in damaged NS is considered as “dangerous” or “extremely dangerous” depending on the accident type and scale.

The radioactive contamination of non-damaged NS is determined principally by ^{60}Co (96%), the remaining 4% are created by ^{137}Cs, ^{90}Sr, ^{144}Ce, ^{54}Mn and ^{55}Fe. In damaged NS stored afloat, the main contaminants are ^{137}Cs or ^{60}Co, depending on the accident type.

Within strict regime zone of WSA storing damaged NS, the radiation situation is characterized as "dangerous". An insignificant surface contamination is also found that indicates the contamination spreading along the main personnel pathways.

Within WSA storing non-damaged NS and in temporary storage centers (TSC) the γ-DR slightly exceeds the natural radiation background only within a radius of few meters from the reactor compartments.

Analyses of samples taken in the environment (marine water, bottom sediments and algae) within the water space of WSA and TSC give background levels, or only a small increase of the specific activity of radionuclides. The maximum activity is found in bottom sediments, intermediate values in algae and minimum values in near-bottom water layers. Elevated radionuclide concentrations are also detected in internals and shells of mollusks. 96 percent of the contamination is due to ^{60}Co and ^{137}Cs.

An analysis of the obtained data demonstrates that the environmental contamination resulting from waterborne storage of the II-nd and IV-th-type NS is due mainly to washout of:

- radioactive substances from the outer surface of the above-water part of NS hull and
- metal corrosion products out of the light hull sections located under both the reactor compartment and compartments being activated by neutrons in the course of PRF operation.

When considering waterborne storage of non-damaged NS containing the core (I-st type) and damaged NS (III-rd type), a further contamination pathway is also possible - unauthorized LRW dumping. Moreover, in the case of depressurizing biological protection tanks (BPT) in NS of waterborne storage and temporary storage and in three-compartment units, contamination can result from corrosion processes of the strong hull possessing high levels of induced activity at some spots.

Calculations demonstrate that in the case of NS prepared for temporary waterborne storage and of three-compartment units (IV-th type) about 0.16 MBq, with respect to one NS, would reach the water space of TSC in the course of 10 to 12 years. Taking into account that the TSC capacity makes up 30 vessels on average, the contamination would reach 4.8 MBq. Such amounts of radioactive substances, even without consideration for deposition on the sea-bottom, would dissolve in the marine water to MAC levels of 40-60 Bq/m^3 and, thus, would not lead to an appreciable increase of the radioactivity within the water space of about some millions of m^3. It is worthy of notice that in the calculations the MAC for drinking water were used.

The above-presented calculated data are confirmed by the results of monitoring over the environment components within TSC. Thus, in the course of three years of waterborne storage of reactor units, no statistically significant contamination in samples of marine water, bottom sediments, algae, soils or vegetation was recorded.

During the same period of time, about 0.11 MBq of radioactive substances would accumulate in the TSC water area when storing “afloat” NS without the core (the II-nd type) and 220 MBq in the case NS with the core (the I-st type). When placing about 30 non-damaged NS within one TSC (including 50% of NS containing the core), up to 3.31 GBq of radioactive substances (mainly ^{60}Co) would reach the water area. This amount is 700 times larger than the corresponding value in the case of NS of the IV-th type.

If depressurizing BPT in NS of waterborne storage or temporary storage, in the 10 to 12-year period about 1.0 through 95 GBq of radioactive substances could reach the water area in addition.

The worst technical state characterizes NS under waterborne storage. As distinct from vessels of the IV-th type, these NS have not been subjected to a special stage of “preparing for temporary waterborne storage”. As a result, in this case the initiation of emergency situations due to NS sinking, primary circuit depressurization or coolant ingress into the marine water is the most probable. Such events could lead to the integral radioactive contamination of about 800 GBq (note that neither corrosion processes nor the core dissolution in the marine water are taken into account). In such a situation the water area contamination would cause a statistically significant increase of the environmental contamination.

Within WSA storing damaged NS, unauthorized LRW dumping into the marine environment in the course of decontamination operations is one of the principal contamination sources responsible for up to 370 TBq of ^{137}Cs and ^{60}Co. As the result, a considerable contamination of the marine water, bottom sediments and aquatic life is possible.

While conventional, the assessed values of the radioactive substance accumulation in the environment media make it possible to compare the degree of radioecological safety, as applied to different types of the decommissioned NS. These calculations allow assessing the efficiency of waterborne storage stages and temporary storage stages and calculating potential population exposure doses while using waters of such areas after WSA or TSC liquidation.

At the present time, all WSA and TSC storing the decommissioned NS are considered as “exclusion zones” in which recreation activities and fishing are forbidden. The results of both investigations of the radiation situation and analyses of the activity of the environment samples demonstrate the following. Even in the case of WSA storing damaged NS, no radioactive contamination outside the exclusion zone is available, whereas the nearest inhabitable areas are situated 5 to 15 km from such zones. As the result, no impact of the radiation factor on the population residing in the vicinity of areas of the decommissioned NS location is found during the considered period of time.

The results presented make possible the following conclusion. From the radioecological point of view, the temporary waterborne storage of the decommissioned NS after a special “preparing” stage (the IV-th type) represents the safest storage mode.

2.2. Radioecological Situation in Plants Dealing with Nuclear Submarine Handling after the Decommissioning

2.2.1. Radioecological Situation at FSUE "SMBE Zvezdochka" and SUE "Sevmach PA"

Under present-day technologies of nuclear submarine handling after the decommissioning, the environmental contamination by technogenic radioactive substances will inevitably increase. It is assumed that already in 2002 the amount of gaseous, liquid and solid radioactive wastes (GRW, LRW and SRW) increased by a factor of 1.3 to 1.5. Thus, in 2002 the quantity of LRW will reach 1000 m^3 and SRW - 150 m^3. In 2003 to 2004, the volume of LRW will make up 1500 m^3, SRW - 200 m^3 per year; in 2005 through 2010 these amounts will reach 2000 m^3 for LRW and 250 m^3 for SRW per year.

Gaseous radioactive wastes are created when dealing with power reactor facilities and in the course of technical operations with open sources of ionizing radiation. These are indoor air of the strict regime zone compartments and vacuumization cylinders as well as the gas of the high-pressure system, which contain radioactive aerosols and noble gases. After a preliminary clean up from aerosols, GRW are released to the atmosphere (GRW release of the integral activity up to 180 MBq/year is allowed by the Environment Protection Department of Arkhangelsk-town [2.3, 2.4]).

GRW amounts generated when handling nuclear submarines of "Delta"-class make up 1500 to 2000 m^3, of "Typhoon"- and "Oscar"- classes up to 3000 m^3. Prevailing radionuclides are ^{60}Co, ^{90}Sr, ^{137}Cs and ^{85}Kr. The volumetric $\Sigma\beta$-activity varies in the range from 0.04 through 400 kBq/m^3. However within large-area sites of the involved enterprises, such minor quantities of technogenic GRW practically do not influence the existent radiation situation of the surface air layer formed basically by natural (dust - ^{40}K and radioactive products of U-Th sequences) and artificial radionuclides (global fallout of ^{90}Sr and ^{137}Cs). According to monitoring data, in the course of nuclear submarine handling operations the concentrations of artificial and technogenic radionuclides taken together do not exceed 0.0001 of the average annual activity limit for the general population [2.5] (Table 2.2).

Table 2.2 Radiation Situation within the Site of State Nuclear Shipbuilding Center in Severodvinsk-Town in Different Years

Object of monitoring	Indices	1991	1995	1996	1997	1998 *	1999 *	2000	Mean	Range
Zvezdochka	Aerosol activity, 10^{-5} Bq/m^3									24-52
	Density of depositions, Bq/m^2·per month									5-17
Sevmash PA**	Aerosol activity, 10^{-5} Bq/m^3									11-28
	Density of depositions, Bq/m^2·per month					11				8-14
Mean for Zvezdochka and Sevmash PA	Dose rate, μR/h	8-20	8-19	10-18	8-20	10-19	10-18	10-19	14	8-20
Town of Severodvinsk	Aerosol activity, Bq/m^3									10-34
	Density of depositions, Bq/m^2·per month									7-11
	Drinking water activity, Bq/m^3									110-127
	Dose rate, μR/h	10-15	10-15	10-15	10-15	10-15	10-15	10-15	13	10-15
Territory of Russia***	Aerosol activity, Bq/m^3									18-20
	Density of depositions, Bq/m^2·per month									42-48

Comments: The density of alpha and beta particles in depositions within sites of enterprises and in Severodvinsk-town corresponds to the radiation background. In 1990 through 2001 the aerosol background in the Russian North made up $(22\pm7)\cdot10^{-5}$ Bq/m^3 whereas the deposition background equaled 10 ± 2 Bq/m^2 per month. For comparison, in the Far East region of Russia these values equaled, respectively, $(22\pm6)\cdot10^{-5}$ Bq/m^3 and 41 ± 5 Bq/m^2 per month during the same period [2.6]). The error of measurements made up 30%.* Within 100-km radius area around Severodvinsk-town Σβ-activity of aerosols made up $(21\pm7)\cdot10^{-5}$ Bq/m^3 in 1998, and $(45\pm10)\cdot10^{-5}$ Bq/m^3 in 1999 (measurements in Arkhangelsk-town). ** Sevmash PA – State Unitary Enterprise (SUE) "Sevmash Production Association (PA)". *** Radioactive contamination of the environment in Russia in 1998 [2.7].

Thus, practically equal mean values of both the volumetric Σβ-activity and the density of depositions at high values of correlation coefficients (0.7-0.9) within sites of the considered enterprises and in Severodvinsk-town indicate the presence of a prevailing and equal in value common radioactive contamination source. Average values for both State Unitary Enterprise

(SUE) “Sevmash Production Association (Sevmash PA)” and Severodvinsk-town are comparable with the corresponding radiation characteristics in the European Russia and Far East region of Russia. By this is meant that they can be considered as global fallout.

At the same time, slightly elevated concentrations of Σβ-activity of aerosols in the air (an average excess by a factor of 1.4 to 1.7) within Federal SUE "State Machine-Building Enterprise (SMBE) “Zvezdochka” indicate that not all working operations related to nuclear submarine handling are accompanied by extremely low GRW releases. The available distinctions in the contamination of surface layer of air between enterprises necessitate individual approach when analyzing the radiation situation within every site.

When considering the results of long-term monitoring over the radiation situation within SUE “Sevmash PA”, which site is immediately adjacent to Severodvinsk-town, the following two conclusions can be reached:

- the process of nuclear submarine handling has only a small impact on the radiation situation in Severodvinsk-town and
- the prevailing portion of the radioactive contamination in Severodvinsk results from global fallout.

These conclusions are confirmed by the results of monitoring over concentrations of Σβ-activity of artificial and technogenic radionuclides in the atmosphere and their variations. Thus, during the last decade the mean concentration of ^{60}Co and ^{90}Sr in aerosols of SUE “Sevmash PA” remained at a constant low level (< 0.0001 of maximum allowable concentration (MAC)) and made up ≤ $(0.3\pm0.4)\cdot10^{-5}$ Bq/m^3. Aerosol concentrations of ^{137}Cs and ^{144}Ce were equal to ≤ $(0.2\pm0.2)\cdot10^{-5}$ Bq/m^3. However, the concentrations for individual radionuclides exceeded the corresponding parameters in Severodvinsk-town by a factor of 1.5-2 on average: in Severodvinsk ^{60}Co-concentrations did not exceed $(0.1\pm0.1)\cdot10^{-5}$ Bq/m^{3,}, ^{90}Sr and ^{137}Cs – ≤ $(0.2\pm0.2)\cdot10^{-5}$ Bq/m^3, ^{144}Ce – ≤ $(0.1\pm0.1)\cdot10^{-5}$ Bq/m^3 (see Tables 2.3 and 2.4).

Table 2.3 Monthly Average Concentrations of Radioactive Substances in Surface Layer of Air within SUE "Sevmash PA" Site and in Severodvinsk-town as Compared to Some Other Territories of Russia with the Background Radiation Level

Territory	***Month***													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Avg**	**Range**
Sevmash PA														
Aerosols, 10^{-5} Bq/m^3														
1993	4.4	7.4	6.3	7.0	5.9	7.8	7.0	7.4	8.1	7.0	6.3	8.0	6.9	4 – 8
1994	8.5	13.7	8.9	9.6	7.8	6.3	6.7	5.9	5.2	9.6	7.7	6.9	8.1	5 –14
Depositions, Bq/m^2·month														
1993	2.4	1.6	2.5	6.9	1.4	5.4	7.4	3.3	8.4	3.5	2.2	3.3	4.0	1 – 8
1994	1.4	2.3	2.3	5.4	23.1	9.8	11.1	5.9	32.1	11.3	7.8	5.3	9.8	1 -32
Severodvinsk														
Aerosols, 10^{-5} Bq/m^3														
1993	8.9	13.0	13.7	12.6	7.8	9.6	8.9	10.0	6.3	9.6	13.0	12.2	10.5	6 – 14
1994	16.6	27.8	24.0	14.1	9.2	9.2	7.0	9.6	7.8	10.4	8.4	9.9	12.8	7 – 24
Depositions, Bq/m^2·month														
1993	1.4	1.4	1.0	5.4	2.7	11.7	4.9	4.9	9.7	19.9	2.6	6.4	6.0	1 – 20
1994	1.0	2.4	1.8	4.3	7.0	14.1	6.1	4.1	28.4	9.4	3.2	4.1	7.2	1 - 28
Background, 100-km zone (Arkhangelsk)														
Aerosols, 10^{-5} Bq/m^3	7.7	8.4	5.0	4.7	4.4	6.7	6.4	4.5	4.8	5.3	4.5	3.9	5.5*	4 – 8
Depositions, Bq/m^2·month	96	54	63	102	63	18	24	21	27	30	33	24	45*	21-102
Onega-town Depositions, Bq/m^2·month	45	48	39	54	27	9	9	6	9	21	12	18	24*	6 –54

Territory	***Month***													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Avg**	**Range**
Background. North of Russia Aerosols ** 10^{-5} Bq/m^3	10.2	13.9	6.4	6.6	5.2	8.3	7.4	6.2	6.6	5.8	11.0	5.1	7.2	6 – 11
Depositions,** Bq/m^2·month	54	54	42	54	36	18	18	24	21	24	27	24	33	18-54

Comments: Values of the long-lived component in both aerosol volumetric activity and density of depositions are given. Measurement error makes up 30%.* values as of 1999. In 1998 average values of these parameters made up 5,4 10^{-5} Bq/m^3, 21 and 15 Bq/m^2·month, respectively. ** - data of 1999 [2.8]. North of Russia – regions of the Russian North under the survey of the Hydrometeorological Service of the Russian Federation.

Table 2.4 Volumetric Activity of Artificial and Technogenic Radionuclides in Aerosols and Soil Depositions within SUE "Sevmash PA" and in Severodvinsk-town (for Different Years)

Year		**Aerosols, 10^{-5} Bq/m^3**								**Depositions, Bq/m^2·month**							
Half year		**SUE "Sevmash PA"**				**Severodvinsk-town**				**SUE "Sevmash PA"**				**Severodvinsk-town**			
		^{60}Co	**^{90}Sr**	**^{137}Cs**	**^{144}Ce**	**^{60}Co**	**^{90}Sr**	**^{137}Cs**	**^{144}Ce**	**^{60}Co**	**^{90}Sr**	**^{137}Cs**	**^{144}Ce**	**^{60}Co**	**^{90}Sr**	**^{137}Cs**	**^{144}Ce**
1991	I	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	0.1	bd	bd
	II	0.3	bd	bd	bd	bd	bd	0.1	bd	bd	0.3	bd	bd	bd	0.2	bd	bd
1992	I	bd	bd	0.2	bd	bd	bd	0.3	bd	bd	bd	bd	bd	bd	bd	0.2	0.2
	II	0.8	0.2	bd	bd	bd	0.2	bd	0.2	-	-	-	-	-	-	-	-
1993	I	-	-	-	-	-	-	-	-	0.2	0.1	0.5	0.4	0.1	0.1	0.4	0.2
	II	0.1	bd	bd	bd	0.1	0.1	0.1	bd	-	0.2	0.1	0.4	-	0.1	0.2	0.2
1994	I	0.1	bd	0.1	0.1	0.1	0.1	0.1	0.2	-	-	-	-	-	-	-	-
	II	bd	0.2	bd	bd	-	-	0.2	-	-	-	-	-	-	-	-	-
1995	I	0.6	bd	bd	0.2	bd	bd	bd	0.1	0.4	0.1	0.3	bd	0.1	0.1	0.2	0.2
	II	bd	bd	bd	0.2	bd	bd	bd	0.1	0.8	1.1	0.4	0.2	0.2	0.1	bd	0.4
1996	I	bd	0.4	bd	bd	bd	0.1	bd	bd	1.4	0.3	bd	0.3	bd	bd	bd	bd
	II	bd	0.2	0.1	0.4	bd	0.4	0.1	0.1	0.1	0.2	11.0	-	0.2	0.1	0.1	-
1997	I	0.1	1.0	bd	-	bd	0.2	bd	-	bd	0.1	bd	-	bd	0.1	0.2	-
	II	bd	0.1	bd	-	bd	bd	bd	-	bd	0.2	bd	-	bd	0.2	bd	-
1998	I	0.2	bd	0.2	-	bd	0.2	0.2	-	bd	0.5	bd	-	bd	0.1	bd	-

Year		Aerosols, 10^{-5} Bq/m^3								Depositions, Bq/m^2·month							
Half year		SUE “Sevmash PA”				Severodvinsk-town				SUE “Sevmash PA”				Severodvinsk-town			
		^{60}Co	^{90}Sr	^{137}Cs	^{144}Ce	^{60}Co	^{90}Sr	^{137}Cs	^{144}Ce	^{60}Co	^{90}Sr	^{137}Cs	^{144}Ce	^{60}Co	^{90}Sr	^{137}Cs	^{144}Ce
	II	bd	0.1	0.4	-	bd	bd	bd	-	0.1	0.6	0.3	-	0.2	0.3	0.2	-
1999	I	bd	bd	bd	-	bd	0.1	bd	-	bd	0.1	2.4	-	bd	0.10.	bd	-
	II	bd	bd	bd	-	bd	bd	bd	-	bd	0.2	bd	-	bd	1	bd	-
2000	I	bd	1.0	bd	-	bd	bd	bd	-	bd	1.8	bd	-	bd	0.1	bd	-
	II	bd	0.1	bd	-	bd	bd	bd	-	bd	0.2	bd	-	bd	0.2	bd	-
X+	1 σ*	0.3	0.3	0.2	0.2	0.1	0.2	0.2	0.1	0.5	0.4	2.1	0.3	0.2	0.1	0.2	0.2

Comments: Bd – below detection limit, * excess over the average value with P ≥ 0.7 (1σ)

When analyzing artificial and technogenic radionuclide concentrations presented in Table 9, the following circumstance is worthy of notice. A consideration of sampled data can lead to an ill-founded conclusion that SUE “Sevmash PA” is responsible for a considerable portion of Severodvinsk-town contamination by technogenic radionuclides in the course of nuclear submarine handling operations (see Table 9, ^{90}Sr and ^{137}Cs values in column “Depositions” for Severodvinsk-town). According to Table 9, maximum values of ^{137}Cs depositions were recorded in 1993, of ^{90}Sr in 1998. ^{90}Sr concentrations in aerosols reached a peak in 1996. These data are comparable with the correspondent parameters recorded within the enterprise site. At the same time, they exceed the mean radiation background level in Russia by a factor of 5 to 10. In accordance with the data of [2.7], in the course of 1993 through 2000 the mean concentrations in Russia made up for ^{90}Sr in aerosols $(0.015\pm0.002)\cdot10^{-5}$ Bq/m^3 and for ^{137}Cs in aerosols $(0.056\pm0.002)\cdot10^{-5}$ Bq/m^3. In depositions ^{137}Cs concentration was equal to 0.08 Bq/m^2·month.

There are several reasons explaining such a situation. Such enterprises as FSUE “SMBE Zvezdochka” and SUE “Sevmash PA” in the Russian North and “Zvezda” Far-Eastern Plant in Far East region of Russia [2.6] are responsible for a portion of the air contamination by technogenic radionuclides due to the technologic process itself which they use. A similar situation is also observed within a 100-km radius area around Krasnojarsk Ore Mining and Chemical Enterprise (OMChE), in towns of Kurchatov and Obninsk, within “Mayak PA” and in other plants performing radiation-dangerous operations. But within the sites of the above-mentioned enterprises, technogenic radionuclide concentrations are below the maximum allowable values for the general population by 5 to 6 orders of magnitude [2.7].

When interpreting the results presented in Table 2.4, there is another difficulty. To identify technogenic radionuclides, methods with sensitivity threshold at a level of 0.00001 MAC are used. But to record artificial radionuclides (i.e., the local level of global fallout), such a threshold is insufficient. It is well known that when measuring extremely low concentrations of radioactive substances close to a sensitivity limit of the methods employed, the error of measurements can increase up to 60-120%. This can lead to gross errors resulting in discrepancies between the results of separated measurements by a factor of 2 to 5 [2.9].

Despite the aforesaid, no considerable distinction between the data of radiation monitoring within SUE “Sevmash PA” site and those of Severodvinsk-town was obtained in the course of the last decade. This indicates the prevailing importance of global fallout in the environmental contamination of Severodvinsk-town.

As mentioned above, within FSUE “SMBE Zvezdochka”, technogenic radionuclide concentrations in aerosols are all-time higher (by a factor of 1.5 to 2 on average) than in SUE “Sevmash PA” or in Severodvinsk-town (see Table 2.2). A similar situation is created in Jagry-settlement, which is immediately adjacent to “Zvezdochka SMBE” site (Table 2.5).

Table 2.5. Average Monthly Variations in Both Volumetric Beta-Activity of Aerosols and Density of Radioactive Depositions Resulting from Radiation-Dangerous Operations Related to Nuclear Submarine Handling within FSUE "SMBE Zvezdochka " and in Jagry-Settlement

Year	***Aerosol taking sample area, specialized section №***						***Deposition taking sample area, specialized section №***					
Month	***150***	***101***	***9***	***6***	***TS-31***	***Jagry***	***150***	***101***	***9***	***6***	***TS-31***	***Jagry***
1998												
January	-	-	-	-	-	-	-	-	-	-	-	-
February	-	-	-	-	-	-	-	-	-	-	-	-
March	-	-	-	-	-	-	-	-	-	-	-	-
April	-	-	-	-	-	-	-	-	-	-	-	-
May	-	-	-	-	-	25	-	-	-	-	-	-
June	-	-	-	47	-	-	-	-	-	-	-	-
July	33	48	29	-	32	25	-	-	-	-	-	-
August	32	53	23	50	21	16	-	-	-	-	-	-
September	-	-	-	56	-	-	-	-	-	-	-	-
October	-	46	32	50	-	19	-	-	-	-	-	-
November	51	56	43	57	38	38	-	-	-	-	-	-
December	-	-	-	54	-	24	-	-	-	-	-	-
Average	39	51	32	52	30	24	-	-	-	-	-	-
Zvezdochka/Jagry	1.6	2.1	1.3	2.2	1.2	1.0*	-	-	-	-	-	-
1999												
January	94	104	102	84	82	84	3.2	-	-	-	-	-
February	90	78	76	65	74	77	2.1	-	-	-	-	-
March	75	56	61	62	65	71	-	-	-	-	-	-
April	53	45	40	-	49	25	-	1.6	-	-	-	-
May	40	52	28	-	-	21	-	6.4	-	-	-	-
June	29	35	25	54	-	16	14.4	-	-	-	-	-
July	41	47	31	-	-	17	7.4	-	-	-	-	-
August	38	45	26	-	-	15	7.0	-	-	-	-	-
September	46	51	39	75	-	22	8.5	6.8	-	-	-	-
October	38	26	30	73	-	17	-	-	-	-	-	-
November	47	58	55	-	-	44	-	-	-	-	-	-
December	38	54	38	-	-	27	2.4	-	-	4.1	3.6	-
Average	52	54	46	69	68	36	6.4	4.9	-	-	-	-
Zvezdochka/Jagry	1.4	1.5	1.3	1.9	-	1.0*	-	-	-	-	-	-
2000												

Year	*Aerosol taking sample area, specialized section №*						*Deposition taking sample area, specialized section №*					
Month	***150***	***101***	***9***	***6***	***TS-31***	***Jagry***	***150***	***101***	***9***	***6***	***TS-31***	***Jagry***
January	71	73	49	-	-	51	3.3	1.2	1.7	-	2.6	-
February	38	43	28	-	-	14	2.4	3.7	1.9	-	1.9	-
March	33	28	30	-	-	24	1.8	1.1	-	-	-	-
April	34	32	32	-	-	16	5.4	3.0	1.7	-	3.0	-
May	35	32	36	-	-	18	5.3	3.6	3.6	-	2.7	-
June	28	31	32	-	-	17	5.4	3.0	1.7	-	3.0	-
July	38	46	50	-	-	28	-	-	-	-	-	-
August	18	23	26	41	-	7	8.3	7.8	3.0	-	1.5	-
September	18	18	21	55	17	8	1.8	3.1	8.1	-	5.2	-
October	34	34	29	49	32	22	7.2	1.5	0.6	-	3.4	-
November	60	55	50	46	57	34	4.8	1.9	2.9	-	4.3	-
December	41	60	40	38	34	34	3.9	2.6	4.0	-	1.8	-
Average	37	39	35	46	35	23	4.2	3.0	2.9	-	2.9	-
Zvezdochka/Jagry	1.6	1.7	1.5	2.0	1.5	1.0	-	-	-	-	-	-

Comments: * - In 1998 Σβ-activity of aerosols within 100-km radius area around Severodvinsk-town made up $(21 \pm 7) \cdot 10^{-5}$ Bq/m^3, in 1999 - $(45 \pm 10) \cdot 10^{-5}$ Bq/m^3 (measurements made in Arkhangelsk-town); TS – transformer substation.

It is worthy of notice that within the North region of Russia such natural background index as Σβ-activity of aerosols varies considerably from year to year (by a factor of 2 through 8 during the last decade, see Tables 2.2, 2.3 and 2.5). Therefore, when analyzing the radioecological situation in enterprises dealing with nuclear submarine handling after the decommissioning, this circumstance should be taken into account every time.

The data of Table 11 demonstrate important distinctions (from a dozen to a hundred times compared to natural radiation background) between the concentrations of technogenic radionuclides in the air in the vicinity of specialized sections within the site of FSUE “SMBE Zvezdochka”. At the same time such a phenomenon is unavailable in the air of Jagry-settlement. That clearly indicates the availability of only local air contamination within FSUE “SMBE Zvezdochka”, which is practically confined to its site (Table 2.6).

Table 2.6 Average Annual and Half-Annual Variations of Technogenic Radionuclide Concentrations in Aerosols and Depositions Resulting from Radiation-Dangerous Operations Related to Nuclear Submarine Handling within FSUE "SMBE Zvezdochka" and in Jagry-Settlement

Year	Half-year	Specialized section	Volumetric activity of aerosols, 10^{-5} Bq/m^3				Density of contamination, Bq/m^2·month			
			A_{sp}	^{60}Co	^{90}Sr	^{137}Cs	A_{dep}	^{60}Co	^{90}Sr	^{137}Cs
1998	-	150	39	0.3	0.2	1.0	-	-	-	-
		101	51	5.6	0.3	0.4	-	-	-	-
		9	32	0.2	0.3	0.6	-	-	-	-
		6	52	1.0	0.1	2.0	-	-	-	-
		TS-31	30	0.9	0.2	1.0	-	-	-	-
		Average	41±5	1.6±0.8	0.2±0.1	0.8±0.5	-	-	-	-
	-	Yagry*	24				-	-	-	-
1999		150	52	-	-	-	6.4	0.8	-	< 0.5
		101	54	2.3	-	4.6	4.9	< 0.1	-	< 0.3
		9	46	1.6	-	9.0	-	< 0.08	-	< 0.2
		6	69	0.2	-	2.1	-	-	-	-
		TS-31	68	1.2	-	3.8	-	< 0.1	-	< 0.2
	-	Average	58	0.1	< 0.1	1.4	5.6±0.4	0.07-0.8	-	-
		Yagry*	36	1.1±0.5	-	4.2±2.2		-	-	-
2000		150	37		-		-	0.7	< 0.2	0.9
		101	39	< 0.04	0.4	< 0.7	4.2	< 0.4	< 0.7	0.8
		9	35	3.8	0.7	1.1	3.0	< 0.3	< 0.2	< 0.3
		6	46	< 0.4	< 0.4	< 3.4	2.9	-	-	-
		TS-31	35	< 0.2	< 0.7	< 0.5	-	< 0.2	< 0.1	< 0.3
		Average	38±3	1.4	< 0.1	1.3	2.9	0.1-0.7	-	0.2-0.9
		Yagry*	23	< 0.05	0.09-0.7	< 0.07	3.2±0.4		-	
				0.04-3.8	< 0.2	0.06-1.3		-		-
				< 0.05		< 0.09	-			
1998	I	150	< 56	0.3	< 0.2	1.5	-	-	-	-
		101	< 53	0.2	< 0.3	0.3	-	-	-	-
		9	< 45	< 0.1	< 0.2	0.2	-	-	-	-
		6	< 56	1.7	< 0.1	1.2	-	-	-	-
		TS-31	< 50	< 0.08	< 0.3	1.2	-	-	-	-
		Jagry	< 43	-	-	-	-	-	-	-
	II	150		0.2		0.4	-	-	-	-

Year	Half-year	Specialized section	Volumetric activity of aerosols, 10^{-5} Bq/m^3				Density of contamination, Bq/m^2·month			
			A_{sp}	^{60}Co	^{90}Sr	^{137}Cs	A_{dep}	^{60}Co	^{90}Sr	^{137}Cs
		101	< 38	11.0	< 0.2	0.4	-	-	-	-
		9	< 52	0.3	< 0.2	1.1	-	-	-	-
		6	< 34	1.4	< 0.4	2.8	-	-	-	-
		TS-31	< 54	< 0.09	< 0.2	0.09	-	-	-	-
		Jagry	< 34	-	< 0.2	-	-	-	-	-
			< 25		-					
1999	I	150	64	3.9	< 0.07	8.4	< 5.5	1.2	< 0.3	0.9
		101	62	1.2	< 0.2	8.4	< 2.5	0.1	< 0.2	0.2
		9	55	0.2	< 0.4	3.8	< 6.0	0.1	< 0.3	0.2
		6	54	1.2	< 0.5	2.6	-	-	-	-
		TS-31	57	0.1	< 0.1	1.4	< 3.4	< 0.1	< 0.3	< 0.2
		Jagry	49	0.05	< 0.08	1.4	-	-	-	-
	II	150	41	0.7	-	0.8	< 5.0	0.4	-	< 0.1
		101	47	1.9	-	9.6	< 6.6	< 0.07	-	0.4
		9	37	0.1	-	0.4	< 4.8	< 0.05	-	< 0.1
		6	53	1.2	-	1.5	-	-	-	-
		TS-31	46	0.1	< 0.1	1.4	< 4.0	< 0.1	-	< 0.1
		Jagry	24	0.03	-	< 0.08	-	-	-	-
2000	I	150	40	5.2	0.3	1.4	-	1.0	< 0.3	1.1
		101	39	0.8	1.0	6.8	2.6	0.6	< 0.3	0.7
		9	34	0.3	< 0.4	1.0	< 2.5	0.2	< 0.08	< 0.2
		6	-	1.8	< 0.2	1.0	-	-	-	-
		TS-31	-	-	-	-	< 2.7	0.2	< 0.1	0.3
		Jagry	23	< 0.06	< 0.2	< 0.1	-	-	-	-
	II	150	35	2.4	0.5	0.7	5.5	0.5	< 0.2	0.7
		101	39	< 0.06	0.3	< 0.04	< 4.3	< 0.2	< 1.1	0.9
		9	36	< 0.04	0.3	< 0.08	3.7	< 0.3	< 0.2	0.4
		6	-	0.9	< 1.1	1.5	-	-	-	-
		TS-31	35	< 0.05	< 0.1	< 0.07	< 4.2	< 0.2	< 0.2	< 0.3
		Jagry	22	< 0.03	< 0.1	< 0.04	-	-	-	-

Comments: * - Within 100-km radius area around Severodvinsk-town Σβ-activity of aerosols in 1998 made up (21±7)·10^{-5} Bq/m^3, in 1999 - (45±10)·10^{-5} Bq/m^3 (measurements made in Arkhangelsk-town)

Thus, when comparing radionuclide concentrations in aerosols and soil depositions (see Tables 2.9 and 2.11), the following conclusion can be reached. The utilization of two submarines per year coupled with day-to-day operation of FSUE “SMBE Zvezdochka” and SUE “Sevmash PA” enterprises results in an increase of technogenic radionuclide concentrations within their sites (as compared to background concentrations in the air) by 20 to 50 times on average for ^{90}Sr and ^{137}Cs. When considering ^{60}Coconcentrations, the increase is several hundred times. However, according to Radiation Safety Standards-99 (RSS-99), these values do not exceed 0.001-0.0001 of MAC. At the same time, the concentrations of the corresponding radionuclides in soil depositions exceed the background level by a factor of 5 to 10 at the most.

There are also distinctions in the air contamination between enterprises. Thus, the releases of technogenic radionuclides by FSUE “SMBE Zvezdochka” exceed those of SUE “Sevmash PA” by a factor of 2 to 7. This is due to the fact that the first-mentioned enterprise performs most of operations related to NS utilization.

2.2.2. Radioecological Situation at SUE "Nerpa" Shipyard

2.2.2.1. Radioactive Contamination of the Environment Components

"Nerpa" Shipyard carries out monitoring over the following components of the environment:

air (measurements of the integral β-activity);
depositions (measurements of the integral β-activity);
marine water (radiochemical analysis);
algae (radiochemical analysis);
dust swept within the slipway (radiochemical analysis); and
snow (measurements of the integral β-activity).

Throughout the period under consideration (i.e., 1989 through 1994) β-activity in the air varied from 0.05 to 0.70 mBq/m^3 at all monitoring points [2.5, 2.6]. These data practically coincide with those of Hydrometeorological Service of Russia on global fallout. Note that the values of volumetric air activity within the slipway, i.e., close to the contamination source, at the enterprise site, and in the town differ only slightly from each other.

In the deposition samples only the integral β-activity is also measured. In the course of the considered period, the contamination density correlated well with the air activity and did not exceed the range of 1.0 - 9.6 Bq/m^2 per month at all measurement points.

The results of snow measurements virtually coincided with the deposition measurements.

Radiochemical analysis of the dust swept in the slipway demonstrated that the density of surface contamination with radioactive dust reached 6.0 Bq/m^2 per month at individual points for ^{60}Co and 1.5 Bq/m^2 per month for ^{137}Cs; in this case the integral β-activity varied within the range 2.3 - 6.8 Bq/m^2 per month. As a rule, the results of dust measurements should be interpreted with care, though in this case they allow concluding that radiation-dangerous work exerts an appreciable impact on the air contamination in the slipway.

As demonstrated by the results presented in Table 2.7, the activity of both algae and marine water is close to the values resulting from global fallout; that is, far below control levels determined by the enterprise. Thus, by the present time no water contamination is recorded within the shipyard as the result of its operation.

Table 2.7 Maximum Volumetric Activity of Individual Radionuclides in Samples of Marine Water and Algae, Bq/L and Bq/kg

Nuclide	**Marine water, Bq/L**	**Algae, Bq/kg**
^{60}Co	3.7±0.9	6±2
^{90}Sr	0.03±0.01	3±1
^{137}Cs	1.7±0.3	2±1

The latest full-scale investigation of the environmental contamination in the area of "Nerpa” shipyard was performed in 1994 by a team of SUE Research Institute of Applied Medicine (RIAM). The investigation was aimed at preparing materials to justify the boundaries of “Nerpa” shipyard buffer area.

The investigation program included taking and analyzing samples in different environmental media, such as: soils, vegetation, aquatic life, air, depositions, effluents, marine water and drinking water, gamma-survey of the territory, and gamma-dose measurements on site using accumulative thermoluminescence dosimeters (TLD).

The sampling points and TLD were arranged in such a way that made it possible to take into account local wind conditions (the dominance of wind from south and southwest in winter and from north in summer) within the buffer area and the radiation-control area. At the same time the sampling points covered all directions including the opposite coast of Olen’ja Bay (Nezametnaja Bay). The basic results of measuring the activity of the environment media at "Nerpa" Shipyard in 1994 are presented in Table 2.8.

Table 2.8 Integral Beta-Activity and Individual Radionuclide Concentrations in Samples of the Environment Media Taken within the Buffer Area and the Radiation-Control Area of "Nerpa" Shipyard in 1994 [2.5]

Sample type		**β- activity**	**^{40}K**	**^{90}Sr**	**^{137}Cs**	**^{239}Pu**	**^{241}Am**
Air μBq/m^3		41 ± 2	<7	<8	<2	-	<0.4
Depositions Bq/m^2·month		6.2 ± 0.2	0.6-4.1	<1.6	<0.3	-	-
Soil (kBq/kg, dry weight)	Buffer area	0.39 ± 0.01	0.1-0.4	-	0.001-0.15	<0.0005	<0.002
	Radiation-control area	0.40 ± 0.005	0.2-0.5	-	0.001-0.11	<0.002	<0.0005
Vegetation (kBq/kg, Dry weight)		0.72 ± 0.03	0.2-0.4	<0.05	0.01-0.05	<0.002	<0.0004
Water, Bq/l	Effluents	0.50 ± 0.11	-	<0.03	<0.04	-	-
	Marine water	<0.06	-	<0.05	<0.04	-	-
	Drinking water	-	-	<0.02	<0.04	-	-
Algae (Bq/kg, raw weight)		180 ± 9	60-280	7-14	0.1-1.1	<1.0	<0.2

In the case of integral beta-activity, average values of the specific activity of every component and their errors (with the confidence probability of 95%) are indicated; for individual nuclides the ranges or the upper measurement limits are given.

The integral volumetric β-activity of the surface layer of air varied mainly from 0.02 mBq/m^3 to 0.2 mBq/m^3, and the activity of ^{137}Cs in the air did not exceed 0.002 mBq/m^3. In some samples ^{90}Sr was found with the activity up to 0.008 mBq/m^3. These data correlated well with the results of deposition measurements (their β-activity varied mainly from 6 to 7 Bq/m^2 per month).

The beta-activity of the environmental components was due principally to ^{40}K of natural origin. The concentration of ^{40}K in soil samples varied within the range of 130-490 Bq/kg of dry sample, in hydrobionts within 60-280 Bq/kg of wet sample, in atmospheric air it increased up to 0.09 mBq/m^3, in soil depositions up to 4.1 Bq/m^2 per month.

The above values are in good agreement with the average values of global fallout. Thus, ^{40}K concentration in the soil varies generally from 100 Bq/kg to 700 Bq/kg [**7**].

The concentrations of global artificial radionuclides (^{90}Sr and ^{137}Cs) in samples of the environmental components taken in 1994 varied within the range characteristic for the location of other shipyard enterprises with background-levels and for the Northwest region of Russia, as a whole.

It is worthy of notice that the obtained soil sample data have comparable difficulties as the results of other investigations, since in most cases the soil contamination is given in a unity of activity per a unity of area (i.e., Ci/km^2 or Bq/m^2). The density of 5-cm soil layer β-contamination calculated from specific β-activity of samples and their specific weight made up 2.8 to 26 GBq/km^2 (0.08-0.7 Ci/km^2); by this is meant that it varied within the natural background oscillations. However, these calculated values should be considered as rather conventional, since in the region studied only a small part of the rock is covered with a thin soil layer.

Thus, the results of monitoring the radiation contamination across different environmental media demonstrate that at present the radiation-dangerous operations carried out by the enterprise exert almost no additional radiation impact on the environment.

2.2.2.2. Gamma Dose Rate Levels

Within the site of "Nerpa" shipyard and the surrounding area an auto-gamma survey was performed along two itineraries:

Itinerary 1 - "Nerpa" shipyard site; and

Itinerary 2 – shipyard passageway – motor road to Snezhnogorsk – Snezhnogorsk-town area – motor route to lake Arno.

Measurements (averaged and maximum values) were recorded at 50 m intervals.

The generalized results of gamma dose rate measurements are demonstrated in Table 2.9. According to these data, on roads within “Nerpa” shipyard site average gamma dose rate values did not exceed the natural radiation background typical for the Northwest region (0.07 – 0.12 μSv/h) in most cases. Similar dose rate values were recorded within the buffer zone, the radiation control zone and in Snezhnogorsk-town. The maximum dose rate values fixed at individual points did not exceed the doubled natural radiation background.

Table 2.9 Gamma Dose Rate within "Nerpa" Shipyard Site and the Surrounding Area [2.6]

Area of auto gamma-survey	**Gamma dose rate, μSv/h**		
	Maximum	**Average**	**Standard deviation**
1. "Nerpa" shipyard site	0.23	0.11	0.02
2. Motor road between the shipyard and Snezhnogorsk (buffer area)	0.18	0.11	0.02
3. Motor road between the shipyard and Snezhnogorsk (radiation control area)	0.19	0.11	0.03
4. Snezhnogorsk-town	0.20	0.11	0.02
5. Motor road between Snezhnogorsk-town and lake "Arno"	0.20	0.11	0.02

In the shipyard buffer area at points of taking soil and vegetation samples (northwest direction) a foot-gamma survey was performed using DRG-01T - type portable dosimeters. The recorded values did not exceed the range of natural background oscillations.

As a whole, when assessing the results of the gamma-survey within "Nerpa" shipyard site and around it, the following conclusion can be reached. At the time of the auto-gamma survey measurements, no radioactive contamination of the territory under investigation was recorded.

Open-air gamma dose rate monitoring using accumulative TLD was carried out at 25 control points located within the shipyard site, in the buffer area and the radiation control area. The dosimeters were exposed for about three months (from 10-12 September to 15-20 December 1994). Some dosimeters placed at the opposite coast of Olen'ja Bay (mounds at the Nezametnaya Bay coast) were inaccessible till the summer 1995 because of winter conditions, i.e., in this case, the exposure time was equal to nine months.

The dispersion of values recorded at every monitoring point by individual dosimeters did not exceed 10% within a 95% confidence interval.

An analysis of the results demonstrates that at almost every control point located in the buffer area and the radiation control area, gamma dose rates extrapolated for one-year period varied within the limits of 0.7 mSv through 0.9 mSv. At the Arno Lake shore (radiation control area) values of gamma dose rate were slightly higher - 1.5 mSv. But no value exceeded the background level typical for the Northwest region or any other region of Russia.

At the same time, there were many points within the shipyard site in which gamma dose rate values were considerably higher. Thus, within the area of SRW collection the annual dose made up 70 mSv, at the special pier - 12 mSv, in the tank-sector of the slipway - 5.5 mSv, in the sector of control rod repair - 1.3 mSv and in the radiometric laboratory - 1 mSv.

2.3. Radioecological Situation at SRE "Atomflot"

"Atomflot" Service and Repair Enterprise (SRE) is situated at the coast of Kola Bay 2-km north from Murmansk-town inhabitable areas. The enterprise performs nuclear vessel maintenance and repair operations. It is also used as permanent basing of Nuclear Maintenance Support Vessels (NMSV) (floating enterprises "Imandra", "Lotta" and "Lepse"; steamship "Volodarskiy"; special-purpose tanker "Serebrianka").

In addition to routine ship-repair operations, the enterprise carries out both repair and reloading of nuclear reactors, repair of reactor equipment, acceptance and processing of SRW and LRW and their temporary storage until transportation for disposal, transportation of non-irradiated and spent nuclear fuel.

2.3.1. Pathways and Sources of the Environment Radioactive Contamination

Radiation-dangerous operations carried out at the enterprise are accompanied by the creation of LRW, SRW and gaseous RW; unfortunately, their impact on the environment cannot be eliminated in full measure. The releases of radioactive substances to the atmosphere reach their maximum in the course of the following operations:

- RW processing (burning of combustible SRW, LRW decontamination, washing of working clothes in special laundries);
- PRF repair and reloading of nuclear icebreaker reactor cores;
- Operations with contaminated equipment within the enterprise sections;
- Storage and operations with SF on NMSV;
- Acceptance and coastal storage of reactor internals and spent fillers of ion-exchange filters; and
- Operations related to SF transportation.

The principal potential source of radionuclide release to the atmosphere at "Atomflot" SRE is the Waste Burning Installation (WBI), when operating. The activity of air released by other SRE sections is several orders of magnitude less [2.8, 2.9].

The purification of WBI combustion gases is performed using gauze filters and different-type anti-aerosol filters. The largest contribution to the activity of purified combustion gases is due to ^{137}Cs (volumetric activity up to 400 Bq/m^3), ^{134}Cs (up to 15 Bq/m^3) and ^{60}Co (up to 5 Bq/m^3). Characteristic values for annual release of different radionuclides are presented in Table 2.10.

When performing core-reloading operations, nuclear vessels represent the second most importance source of atmospheric contamination.

When reloading the core, radioactive gases and aerosols can be released to the near-vessel air, as follows:

- via mainmast (in an organized way) when releasing pressure prior to beginning dismantling operations;
- through the ventilation system of the central compartment (via mainmast) in an organized way during reloading operations; and
- via occasionally opened hatches of the equipment room in non-organized way.

By way of example, the radionuclide composition of the releases in the course of fuel reloading on "Siberia" nuclear icebreaker in 1982 and in 1986 are also given in Table 2.10. From the radiation point of view the first reloading operation was one of the most unfortunate, the second should be considered as successful. In the course of reloading operations on different vessels performed after 1986 the integral radionuclide release was below that of "Siberia" nuclear icebreaker in 1986; the contribution of transuranium elements was considerably less.

Table 2.10 Annual Radionuclide Releases in the Course of "Atomflot" SRE Operation and when Reloading Nuclear Fuel on "Siberia" Nuclear Icebreaker [2.8, 2.9]

Radionuclide	**WBF release, MBq/year**	**Release when reloading, MBq/year**	
		1982	**1986**
Krypton-85	-	$2.0*10^7$	$3.4*10^4$
Xenon-133	-	$8.0*10^6$	$1.4*10^4$
Chrom-51	200	-	-
Manganese-54	200	1.3	0.73
Cobalt-58	200	2.9	1.3
Cobalt-60	1100	1.4	1.7
Strontium-90	370	-	-
Zirconium-95	200	100	5.5
Niobium-95	200	390	67
Ruthenium-103	-	37	13
Ruthenium-106	-	10	6.8
Antimony-125	200	-	-
Cesium-134	2100	4.7	8.6
Cesium-137	3600	4.3	26
Cerium-141	200	61	2.7
Cerium-144	520	310	52
Europium-152	630	24	5.6
Europium-154	370	10	20
Europium-155	200	-	-
Gadolinium-153	-	250	5.9
Terbium-160	-	49	1.4
Plutonium-238	-*	0.11	0.66
Plutonium-239	-	0.058	0.33

Radionuclide	WBF release, MBq/year	Release when reloading, MBq/year	
		1982	1986
Plutonium-241	-	5.8	33
Americium-241	-	0.029	0.17
Curium-242	-	0.072	0.41
Curium-244	-	0.014	0.083

Comment: * - No analysis of transuranium elements was performed in combustible gases of WBI.

From the data of Table 2.10 it follows that, when reloading, the release of aerosol-generating nuclides is considerably less than the annual WBI release even with consideration that during a one-year period, two or three fuel reloading operations can be carried out by SRE (on different vessels). When assessing exposure doses on the population, radioactive gas releases are rather important, but in the case under consideration their contribution to the environmental contamination is minor.

The calculated values of volumetric β-activity of radioactive aerosols in near-surface air layer being created by the releases of different installations located at "Atomflot" SRE site (both the territory and water area) are given in Table 2.11 [2.9].

Table 2.11 Calculated Values of Volumetric β-Activity of Radioactive Aerosols in the Near-Surface Air Layer Resulting from Releases of Different Installations, Bq/m³

Distance m	Long-duration operational release, Bq					Reloading
	SRE	Nuclear Vessel	Imandra	Lotta	Lepse	Siberia 82
	$1.0 \cdot 10^{10}$	**$7.7 \cdot 10^{07}$**	**$7.8 \cdot 10^{08}$**	**$2.6 \cdot 10^{08}$**	**$5.9 \cdot 10^{09}$**	**$1.2 \cdot 10^{09}$**
$1.0 \cdot 10^{02}$	$3.81 \cdot 10^{-04}$	$1.33 \cdot 10^{-06}$	$5.08 \cdot 10^{-05}$	$2.19 \cdot 10^{-05}$	$5.08 \cdot 10^{-04}$	$2.55 \cdot 10^{-01}$
$1.5 \cdot 10^{02}$	$3.17 \cdot 10^{-04}$	$1.37 \cdot 10^{-06}$	$3.49 \cdot 10^{-05}$	$1.43 \cdot 10^{-05}$	$3.17 \cdot 10^{-04}$	$2.08 \cdot 10^{-01}$
$2.0 \cdot 10^{02}$	$2.48 \cdot 10^{-04}$	$1.11 \cdot 10^{-06}$	$2.57 \cdot 10^{-05}$	$1.08 \cdot 10^{-05}$	$2.44 \cdot 10^{-04}$	$1.50 \cdot 10^{-01}$
$2.5 \cdot 10^{02}$	$1.97 \cdot 10^{-04}$	$8.89 \cdot 10^{-07}$	$2.03 \cdot 10^{-05}$	$9.21 \cdot 10^{-06}$	$2.06 \cdot 10^{-04}$	$1.04 \cdot 10^{-01}$
$3.0 \cdot 10^{02}$	$1.59 \cdot 10^{-04}$	$7.30 \cdot 10^{-07}$	$1.75 \cdot 10^{-05}$	$7.94 \cdot 10^{-06}$	$1.84 \cdot 10^{-04}$	$7.75 \cdot 10^{-02}$
$3.5 \cdot 10^{02}$	$1.33 \cdot 10^{-04}$	$6.03 \cdot 10^{-07}$	$1.59 \cdot 10^{-05}$	$7.30 \cdot 10^{-06}$	$1.68 \cdot 10^{-04}$	$5.90 \cdot 10^{-02}$
$4.0 \cdot 10^{02}$	$1.17 \cdot 10^{-04}$	$4.76 \cdot 10^{-07}$	$1.46 \cdot 10^{-05}$	$6.67 \cdot 10^{-06}$	$1.52 \cdot 10^{-04}$	$4.63 \cdot 10^{-02}$
$4.5 \cdot 10^{02}$	$1.05 \cdot 10^{-04}$	$4.13 \cdot 10^{-07}$	$1.33 \cdot 10^{-05}$	$6.03 \cdot 10^{-06}$	$1.40 \cdot 10^{-04}$	$3.82 \cdot 10^{-02}$
$5.0 \cdot 10^{02}$	$9.52 \cdot 10^{-05}$	$3.49 \cdot 10^{-07}$	$1.27 \cdot 10^{-05}$	$5.71 \cdot 10^{-06}$	$1.30 \cdot 10^{-04}$	$3.13 \cdot 10^{-02}$
$5.5 \cdot 10^{02}$	$9.21 \cdot 10^{-05}$	$2.98 \cdot 10^{-07}$	$1.17 \cdot 10^{-05}$	$5.08 \cdot 10^{-06}$	$1.17 \cdot 10^{-04}$	$2.66 \cdot 10^{-02}$

$6.0 \cdot 10^{02}$	$8.57 \cdot 10^{-05}$	$2.60 \cdot 10^{-07}$	$1.11 \cdot 10^{-05}$	$4.76 \cdot 10^{-06}$	$1.08 \cdot 10^{-04}$	$2.31 \cdot 10^{-02}$
$6.5 \cdot 10^{02}$	$8.25 \cdot 10^{-05}$	$2.32 \cdot 10^{-07}$	$1.05 \cdot 10^{-05}$	$4.44 \cdot 10^{-06}$	$1.02 \cdot 10^{-04}$	$1.97 \cdot 10^{-02}$
$7.0 \cdot 10^{02}$	$7.94 \cdot 10^{-05}$	$2.06 \cdot 10^{-07}$	$9.84 \cdot 10^{-06}$	$4.13 \cdot 10^{-06}$	$9.21 \cdot 10^{-05}$	$1.74 \cdot 10^{-02}$
$7.5 \cdot 10^{02}$	$7.62 \cdot 10^{-05}$	$1.84 \cdot 10^{-07}$	$9.21 \cdot 10^{-06}$	$3.81 \cdot 10^{-06}$	$8.57 \cdot 10^{-05}$	$1.50 \cdot 10^{-02}$
$8.0 \cdot 10^{02}$	$7.30 \cdot 10^{-05}$	$1.65 \cdot 10^{-07}$	$8.57 \cdot 10^{-06}$	$3.49 \cdot 10^{-06}$	$7.94 \cdot 10^{-05}$	$1.39 \cdot 10^{-02}$
$8.5 \cdot 10^{02}$	$6.98 \cdot 10^{-05}$	$1.49 \cdot 10^{-07}$	$8.25 \cdot 10^{-06}$	$3.17 \cdot 10^{-06}$	$7.62 \cdot 10^{-05}$	$1.16 \cdot 10^{-02}$
$9.0 \cdot 10^{02}$	$6.67 \cdot 10^{-05}$	$1.37 \cdot 10^{-07}$	$7.62 \cdot 10^{-06}$	$3.05 \cdot 10^{-06}$	$6.98 \cdot 10^{-05}$	$1.08 \cdot 10^{-02}$
$9.5 \cdot 10^{02}$	$6.35 \cdot 10^{-05}$	$1.24 \cdot 10^{-07}$	$7.30 \cdot 10^{-06}$	$2.86 \cdot 10^{-06}$	$6.67 \cdot 10^{-05}$	$9.84 \cdot 10^{-03}$
$1.0 \cdot 10^{03}$	$6.35 \cdot 10^{-05}$	$1.14 \cdot 10^{-07}$	$6.98 \cdot 10^{-06}$	$2.67 \cdot 10^{-06}$	$6.03 \cdot 10^{-05}$	$8.91 \cdot 10^{-03}$
$1.5 \cdot 10^{03}$	$4.44 \cdot 10^{-05}$	$4.76 \cdot 10^{-08}$	$4.13 \cdot 10^{-06}$	$1.56 \cdot 10^{-06}$	$3.49 \cdot 10^{-05}$	$4.28 \cdot 10^{-03}$
$2.0 \cdot 10^{03}$	$3.14 \cdot 10^{-05}$	$2.19 \cdot 10^{-08}$	$2.92 \cdot 10^{-06}$	$1.05 \cdot 10^{-06}$	$2.38 \cdot 10^{-05}$	$2.66 \cdot 10^{-03}$
$2.5 \cdot 10^{03}$	$2.41 \cdot 10^{-05}$	$1.05 \cdot 10^{-08}$	$2.16 \cdot 10^{-06}$	$7.62 \cdot 10^{-07}$	$1.75 \cdot 10^{-05}$	$1.85 \cdot 10^{-03}$
$3.0 \cdot 10^{03}$	$1.90 \cdot 10^{-05}$	$5.40 \cdot 10^{-09}$	$1.68 \cdot 10^{-06}$	$5.71 \cdot 10^{-07}$	$1.33 \cdot 10^{-05}$	$1.27 \cdot 10^{-03}$
$3.5 \cdot 10^{03}$	$1.56 \cdot 10^{-05}$	$3.05 \cdot 10^{-09}$	$1.33 \cdot 10^{-06}$	$4.76 \cdot 10^{-07}$	$1.05 \cdot 10^{-05}$	$1.03 \cdot 10^{-03}$
$4.0 \cdot 10^{03}$	$1.30 \cdot 10^{-05}$	$1.78 \cdot 10^{-09}$	$1.11 \cdot 10^{-06}$	$3.81 \cdot 10^{-07}$	$8.57 \cdot 10^{-06}$	$8.33 \cdot 10^{-04}$
$4.5 \cdot 10^{03}$	$1.11 \cdot 10^{-05}$	$1.08 \cdot 10^{-09}$	$9.21 \cdot 10^{-07}$	$3.17 \cdot 10^{-07}$	$7.30 \cdot 10^{-06}$	$6.94 \cdot 10^{-04}$
$5.0 \cdot 10^{03}$	$9.84 \cdot 10^{-06}$	$6.98 \cdot 10^{-10}$	$7.94 \cdot 10^{-07}$	$2.76 \cdot 10^{-07}$	$6.35 \cdot 10^{-06}$	$5.90 \cdot 10^{-04}$

The integral volumetric beta-activity of effluent waters varies generally within the range of 1.3-11.6 Bq/L. The radioactive contamination is due mainly to ^{137}Cs, radionuclides of ^{90}Sr, ^{60}Co and ^{154}Eu are also available.

The alpha-activity of transuranium elements (^{238}Pu, ^{239}Pu, ^{241}Am) in effluent waters makes up about 0.11 Bq/L; ^{238}Pu is responsible for up to 90% of the transuranide activity.

2.3.2. Radioactive Contamination of the Environment Media by "Atomflot" SRE

Atmospheric Air

Within the site of "Atomflot" SRE there are six Radiation Monitoring Stations (RMS), in which permanent sampling of the air and depositions is carried out:

RMS-1 – SRE passageway,
RMS-2 – roof of the canteen,
RMS-3 – principal berth,
RMS-4 – SRW storage,
RMS-5 – deck of "Imandra" FSE, and

RMS-6 – the 4th icebreaker bridge near hatches of the equipment room.

For purposes of studying SRE impact on the environment of surrounding territories, samples of atmospheric air and depositions are also taken at the following monitoring points:

point 1 – roof of the building of State Regional Sanitary and Epidemiological Inspection (Murmansk-town center), and

point 2 – Rosta-settlement.

Samples at RMS-6 are taken only in the case of nuclear icebreaker fuel reloading operations.

Table 2.12 presents average values and ranges of variations of the volumetric β-activity in the atmospheric air in the course of reloading operations during 1984 through 1991. Average values of the integral volumetric α- and β-activity and individual radioniclide activities in samples of near-surface air during 1992 through 1994 (the results of gamma-spectrometric and radiochemical analyses) are also given in the Table 2.12.

Principal contribution to β-activity of the atmospheric air is due to ^{137}Cs. Alpha-emitting transuranides, such as ^{238}Pu (up to 0.24 μBq/m^3), ^{239}Pu (up to 0.15 μBq/m^3) and ^{241}Am (up to 0.05μBq/m^3) are found in air samples. As a whole, the measured data confirm the results of calculated estimations given in Figure 2.1.

Table 2.12 Radioactive Contamination of the Atmospheric Air, μBq/m^3 [2.9]

Sampling point	Sampling period	Alpha-activity	Beta-activity	Cs-137	Sr-90
RMS -1	Reloading period; average	-	970±310	-	-
	Variation range	-	260-2400	-	-
RMS -2	Reloading period; average	-	340±90	-	-
	Variation range	-	150-640	-	-
	Average of 1992	48 ±15	220±70	93±40	11±4
	Average of 1993	62 ±25	290±80	10±4	-
	Average of 1994	-	-	-	-
RMS -3	Reloading period; average	-	390±120	-	-
	Variation range	-	170-700	-	-
RMS -4	Reloading period; average	-	310±120	-	-
	Variation range	-	160-610	-	-

	Average of 1992	64 ±28	260±90	91±35	9±4
	Average of 1993	83±32	260±100	86±37	-
	Average of 1994	-	160±50	-	-
RMS -5	Reloading period; average	-	580±200	-	-
	Variation range	-	300-1070	-	-
	Average of 1992	37 ±15	270±100	65±28	7±3
	Average of 1993	67 ±27	430±140	180±67	-
	Average of 1994	-	420±140	-	-
RMS -6	Reloading period; average	-	6500±2550	-	-
	Variation range	-	300-30700	-	-
	Average of 1993	140±45	230 ±100	-	-
	Average of 1994	-	370 ±150	-	-
Murmansk-town center	Reloading period; average	-	220 ±50	-	-
	Variation range	-	80-380	-	-
Rosta-settlement	Reloading period; average	-	180 ±50	-	-
	Variation range	-	70-440	-	-

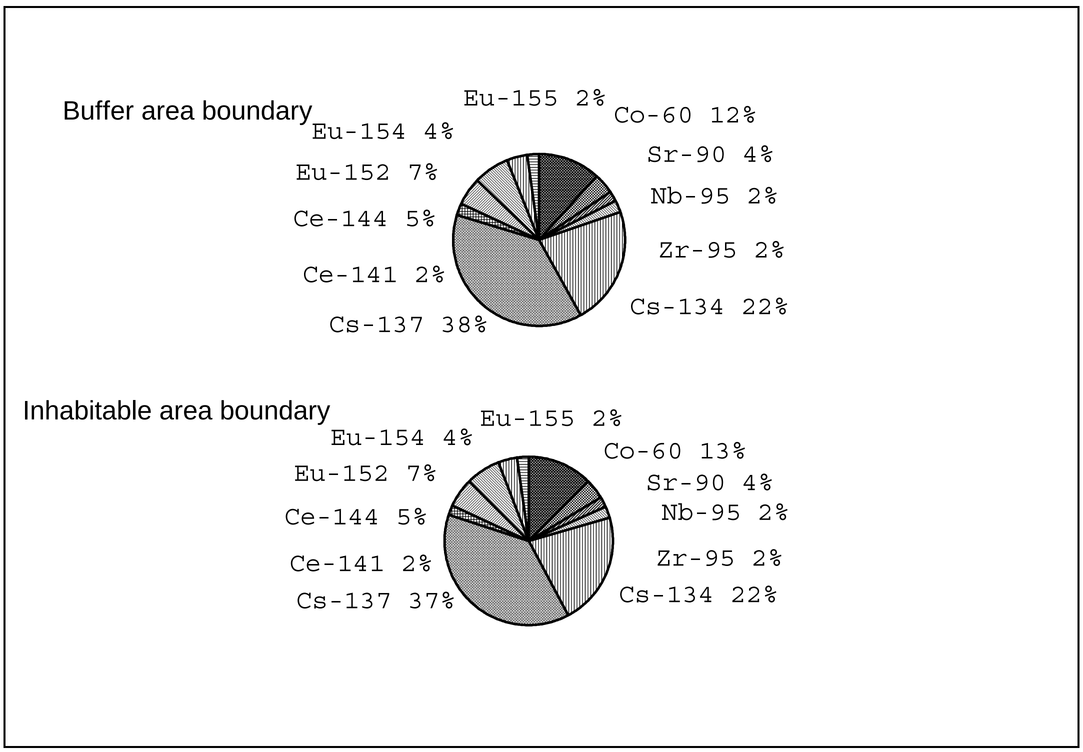

Figure 2.1. Radionuclide Composition of the Activity in Near-Bottom Layer of the Air at the Boundary of the Buffer Area and Inhabitable Area (Calculated Estimation)

To estimate the risk of the atmospheric air contamination, the value of 5 mBq/m^3 of its integral volumetric beta-activity was taken, as a possible criterion. This value approximately corresponds to a maximum annual effective dose of 1 μSv/year. To the above criterion, the following estimation criteria of the volumetric activity of individual radionuclides approximately corresponds: ^{137}Cs - 4.8 mBq/m^3, ^{90}Sr - 0.3 mBq/m^3.

From the data presented it follows that the volumetric activity of 5 mBq/m^3 was surpassed only on the fourth icebreaker bridge (RMS-6), i.e., in the immediate vicinity of the opened hatch of the equipment room when unloading fuel. At the remaining RMS (within "Atomflot" SRE site as well as in Murmansk-town), this value was surpassed neither during fuel reloading operations nor between reloadings.

Radioactive Depositions

Average values and ranges of the density of atmospheric depositions in Murmansk-town and within the site of "Atomflot" SRE during the periods of nuclear icebreaker fuel reloading, as well as average annual values for 1992 and 1993, are presented in Table 2.13.

To determine a criterion aimed at assessing the presented results, one can use the averaged coupling factor between the volumetric air activity and the density of atmospheric depositions recommended by the State Hydrometeorological Service of the Russian Federation. In this case, as a first approximation, the density of atmospheric depositions of 37 Bq/m^2 per month will correspond to the accepted earlier criterion of air contamination risk of 5 mBq/m^3.

Table 2.13 Integral Alpha - and Beta-Activity of Depositions, Bq/m^2·month

Sampling point	Sampling period	Alpha-activity	Beta-activity
RMS -1	Reloading period; average	-	21±7
	Variation range	-	9-50
RMS -2	Reloading period; average	-	330±90
	Variation range	-	8-1740
	Average of 1992	-	24±9

	Average of 1993	6.0 ±2.0	35±11
RMS -3	Reloading period; average	-	22±7
	Variation range	-	8-46
RMS -4	Reloading period; average	-	33±10
	Variation range	-	10-64
	Average of 1992	-	32±10
RMS -5	Average of 1992	-	44±17
	Average of 1993	7.2±2.5	37±16
Murmansk-town center	Reloading period; average	-	8±4
	Variation range	-	2-31
Rosta-settlement	Reloading period; average	-	11±4
	Variation range	-	4-31

After 1984, this criterion was surpassed neither in Murmansk nor in Rosta-settlement. The maximum (of the presented) values in Murmansk center and in Rosta settlement were recorded in July 1986 and were due to the Chernobyl accident rather than to "Atomflot" SRE operation.

Within the site of "Atomflot" SRE, the considered criterion was surpassed principally during nuclear fuel reloading operations. In the course of the period under consideration, the maximum depositions activities were recorded in April 1990 when reloading fuel on the "Russia" nuclear icebreaker – in this case, at RMS-2 (canteen roof) the criterion was surpassed by a factor of 50. In most cases, periods of time with elevated density of depositions coincided with those of elevated volumetric activity in the air.

In the course of subsequent years, annual average values of the integral β-activity of depositions never exceeded the considered criterion throughout the "Atomflot" SRE site. At the same time, a peculiar phenomenon engages our attention. From time to time at some control points an increase of average monthly values above the criterion, which last many months, was also recorded; e.g., such an increase took place during five months in the first half year 1992 (RMS-5), in the third quarter of 1992 (RMS -4), and in the fourth quarter of 1993 (RMS -2).

Thus, the results of monitoring confirm that appreciable amounts of radioactive substances are released in the atmosphere in the course of fuel reloading operations as well as during other radiation-dangerous work (e.g., when operating WBF).

Snow, Soil and Vegetation

Generalized data on the integral β-activity of samples of snow, soils and vegetation taken within the buffer area and the radiation control area of "Atomflot" SRE are presented in Table 2.14.

Table 2.14 Integral β-Activity of Snow, Soil and Vegetation in the Buffer Area and the Radiation Control Area of "Atomflot" SRE in 1992 and 1993

Sampling point	Snow, Bq/m^2		Soil (dry weight), kBq/kg		Vegetation (raw mass), kBq/kg	
Years	**1992**	**1993**	**1992**	**1993**	**1992**	**1993**
"Atomflot" SRE site						
1. Passageway (mound)	108	170	0.72±0.21	0.49±0.15	0.066±0.021	0.042±0.014
2. Boiler-house	94	79	0.65±0.18	0.43±0.15	0.057±0.020	0.068±0.023
3. Repair complex area	66	205	0.48±0.15	0.54±0.15	0.039±0.014	0.070±0.023
4. NS berth	67	246	1.56±0.42	0.54±0.16	0.069±0.020	0.052±0.017
Radiation control area						
5. Abram-Cape village	56	-	1.13±0.35	-	0.067±0.020	0.070±0.020
6. Mishukovo-village (school)	51	-	0.82±0.32	-	0.077±0.022	0.094±0.035
7. Mishukovo-village (center)	70	-	0.72±0.22	-	0.099±0.040	0.078±0.020
8. Belokamenka-village	28	-	0.54±0.16	-	0.069±0.019	0.068±0.020

According to estimations, in 1992 and 1993 the integral beta-activity of snow within the "Atomflot SRE" site made up 12-25 Bq/m^2 per month. With consideration for the different methods used, these estimations were close to the corresponding values of direct measurements performed at the same period (24 to 44 Bq/m^2 per month). The integral beta-activity of snow within the buffer area was virtually equal to that in the radiation control area.

The results of measurements of both the soil and the vegetation activity were in good agreement with those of calculated estimations (Figure 2.2) and demonstrated the following:

during 1992 through 1994 the average specific β-activity of the soil varied within the range of 0.4 up to 1.6 kBq/kg. It did not increase in time and was determined principally by ^{40}K (up to 90 %);

^{137}Cs concentration in the soil varied within a larger range than the average β-activity but did not exceed 40 % of ^{40}K concentration. The activity of ^{90}Sr in the soil was below that of ^{137}Cs;

the concentration of transuranides (^{238}Pu, $^{239+240}Pu$, ^{241}Am) in the soil was very minor (below 2.5 Bq/kg) and made up 1% at the most of the concentration of α-emitting nuclides of thorium and uranium families. The dominance of ^{238}Pu over ^{239}Pu in most samples apparently indicates the reactor origin of the contamination; and

β-activity of vegetation samples was due mainly to ^{40}K concentrations. The integral activity of ^{137}Cs and ^{90}Sr did not exceed 20% of ^{40}K activity.

The values of specific α- and β-activity in soil and vegetation samples in the buffer area and the radiation control area were practically the same. This clearly indicated the unavailability of appreciable (from the point of view of the population exposure) contamination of both the soil and vegetation resulting from SRE operation.

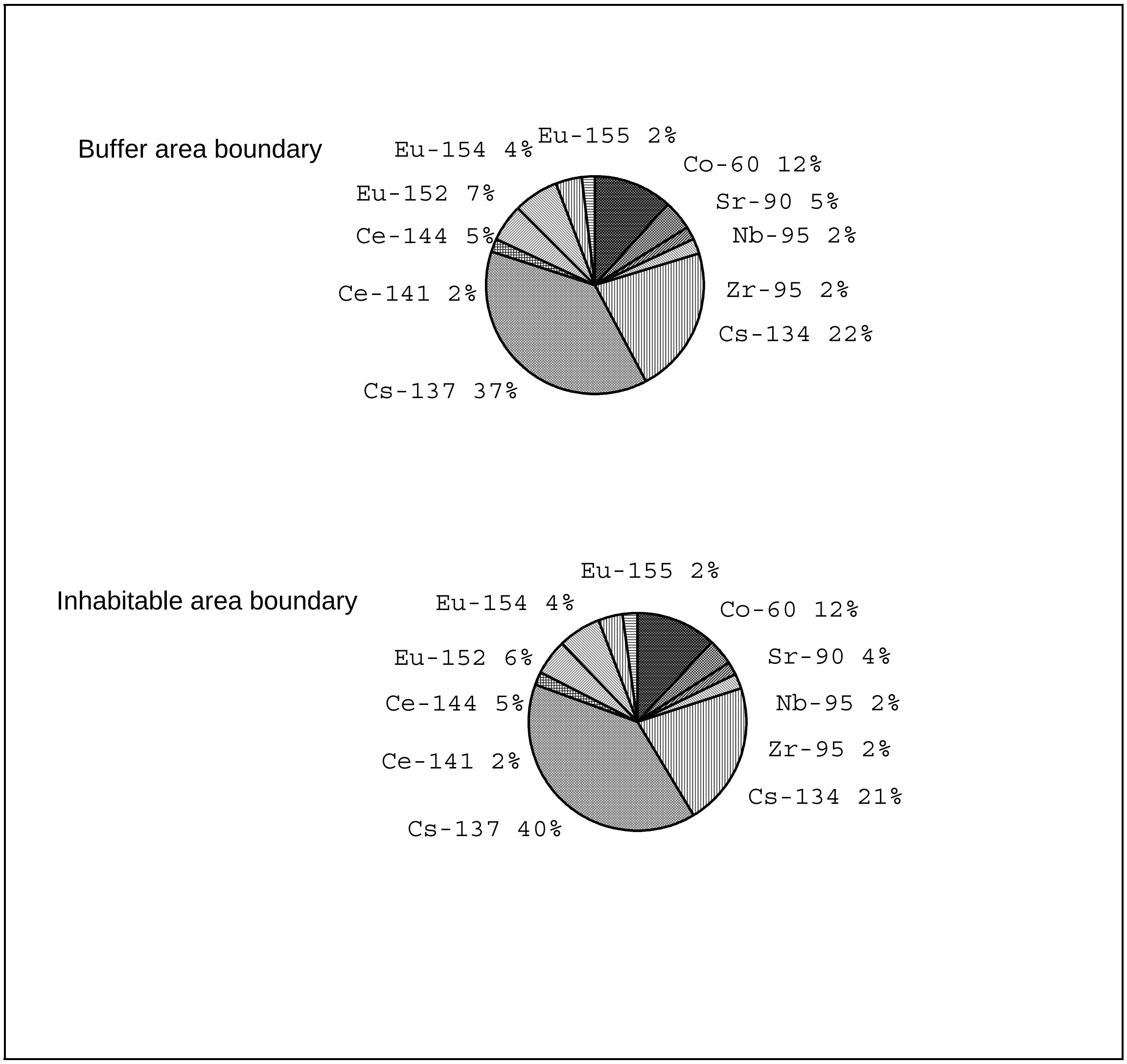

Figure 2.2. Radionuclide Composition of the Soil Activity at the Boundary of the Buffer Area and Inhabitable Area (Calculated Estimation)

Marine Water, Algae and Bottom Sediments

Within “Atomflot” SRE water area, samples of marine water are taken every month and samples of algae and bottom sediments once a year. The results of studying radionuclide concentrations within the considered media are generalized in Table 2.15. Table 2.16 shows the results of individual samples taken in July 1994.

Table 2.15 Volumetric Beta–Activity of Marine Water, Specific β- Activity of Algae and Bottom Sediments

Sampling point	Sampling period	Marine water, Bq/l	Algae (raw mass), kBq/kg	Bottom sediments (dry weight), kBq/kg
Main berth area	1992	-	0.16 ± 0.02	0.86 ± 0.06
	1993	-	0.17 ± 0.01	1.09 ± 0.09
Remote berth area	1992	15 ± 4	0.21 ± 0.01	0.70 ± 0.06
	1993	10 ± 4	0.12 ± 0.01	0.89 ± 0.07
	1 quart.	14 ± 4	-	-
	2 quart.	13 ± 4	-	-
	3 quart.	6 ± 2	-	-
	4 quart.	6 ± 2	-	-

Table 2.16 Specific α- and β-Activity and Concentrations of Individual Radionuclides in Samples of Algae and Bottom Sediments Taken within "Atomflot" SRE Water Area in July 1994, kBq/kg

Sample type	Alpha-activity	Beta-activity	K-40	Cs-137
Algae (raw mass)	0.04	0.18	0.16	0.005
Bottom sediments (dry weight)	1.7	0.71	0.50	≤ 0.001

From the data of Table 2.15 and Table 2.16 it follows that the integral volumetric β-activity of the marine water samples taken monthly in the remote berth area makes up (6-15) Bq/L and is due mainly to ^{40}K. It is obvious that variations in Kola Bay salinity resulting from ebbs and flows as well as from changes in the Kola River runoff can influence considerably the β-activity in the bay waters. As a whole, the β-activity of the Kola Bay water is comparable with the volumetric activity of ^{40}K in ocean water, which varies within the range of (9-12) Bq/L.

^{40}K also determines the specific beta-activity in samples of algae and bottom sediments. ^{137}Cs content does not exceed 5% of ^{40}K concentration.

Thus, as a first approximation, one can conclude that there is no radioactive contamination of the Kola Bay water area in the vicinity of "Atomflot" SRE.

2.3.3. Equivalent Gamma Doses in the Environment

Equivalent gamma doses were measured within “Atomflot” SRE site and in its vicinity in September through November 1994 using accumulative TLD.

Two TLD sets (containing three LiF-based indicators each) were placed at every control point. The dispersion of measurements taken at every control point did not exceed 10% at 95% confidence probability.

The measurement result analysis demonstrates that at most control points located within "Atomflot" SRE site, as well as at the points along the road to Rosta-settlement which is equivalent doses extrapolated for a one-year period varied within the range 1-1.5 mSv, typical of the gamma-background of the Northwest Russia. Here the gamma-background exceeds the corresponding all-Russia average value because of specific geological conditions, i.e., the emergence of granites with elevated natural radionuclide concentrations.

However at some points located along the main berth, gamma levels were considerably higher that was due to the presence of servicing vessels at the berth. The maximum value of 10 mSv/year was recorded when a TLD was placed opposite the special Navy tanker containing LRW.

At the main berth, the average dose value obtained using TLD arranged on portal crane supports made up 1.9 mSv/year, which exceeded by about twice the background value. Note that on supports nearest to the berth, the average value equaled 2.3 mSv/year, and the dose on the most remote supports made up 1.4 mSv/year.

The data obtained were in close agreement with the results of the foot- and auto-gamma-survey performed in the region under consideration in September 1994. In keeping with these data, an area 30-35 m length was found near the repair building with equivalent dose rate up to 0.62 μSv/h, which exceeded the background level by a factor of about five. Individual points with double excess over the background were also recorded along the itinerary. According to the results of auto-gamma-survey (129 measurements), the average dose rate within “Atomflot” SRE site made up 0.17±0.01 μSv/h. This value differed slightly (though statistically appreciably) from the background value of 0.13±0.005 μSv/h (average of 101 measurements) recorded on the motor road SRE – Murmansk-town.

The highest levels were recorded when performing the foot-gamma-survey along the SRE mooring line (168 measurements). Thus, in the mooring area of FSE "Imandra" (which performs fuel reloading operations from nuclear icebreakers and is being also used as a floating storage facility for SF and SRW), the gamma dose rate made up 1.4 μSv/h. Elevated dose rate values were also recorded in the vicinity of other NMSV: "Volodarskiy" - 1.2 μSv/h, "Lotta" - 0.93 μSv/h, special Navy tanker - 0.53 μSv/h, which stores important amounts of RW. It is worthy of notice that during the period under consideration the NMSV mooring areas changed; correspondingly, the radiation situation on the berth changed also. The average dose rate value along the mooring line made up 0.27±0.06 μSv/h.

2. 4. Radioecological Situation at Coastal Servicing Enterprises (CSE)

Coastal servicing enterprises (CSE) of the Russian Navy located in Andreeva Bay and Gremikha settlement were built in early sixties to reload reactors, and to store spent fuel and radioactive wastes.

At present these CSE are decommissioned from the Navy, transferred to Ministry of Atomic Energy (Minatom) of the Russian Federation and are to be rehabilitated as nuclear and radiation-dangerous enterprises wherein important amounts of RW and SF are stored.

2.4.1. CSE in Andreeva Bay (Branch №1 of SFUE "SevRAO")

CSE in Andreeva Bay is situated in Motovskiy Bay of the Kola Peninsula at the west coast of West Litsa Bay (Figure 2.3). Principal one to three storied buildings and installations were built within the CSE site in 1960 through 1965. The CSE site area is equal to 230 000 m^2.

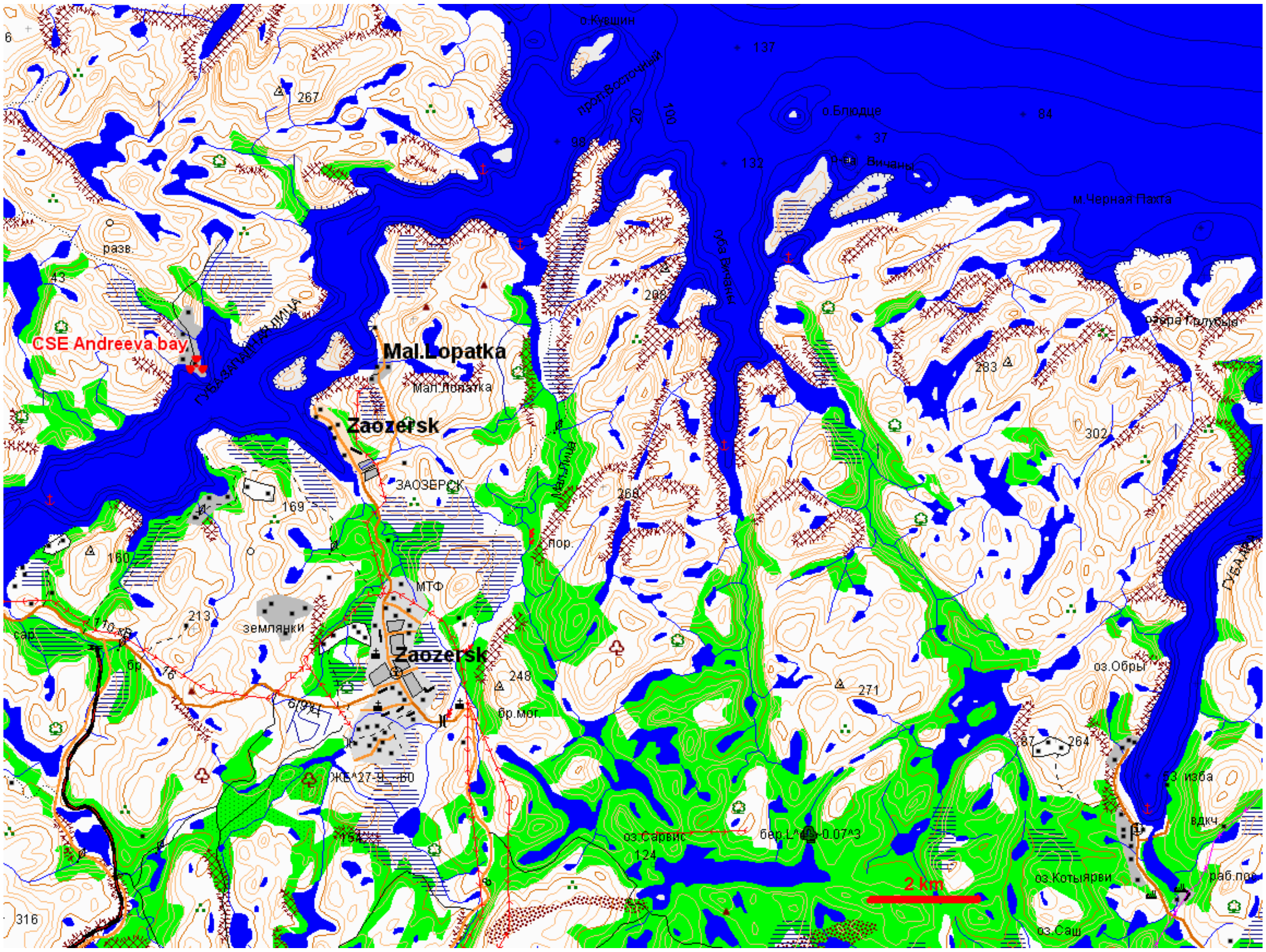

Figure 2.3. Map of the Neighborhood of CSE in Andreeva Bay

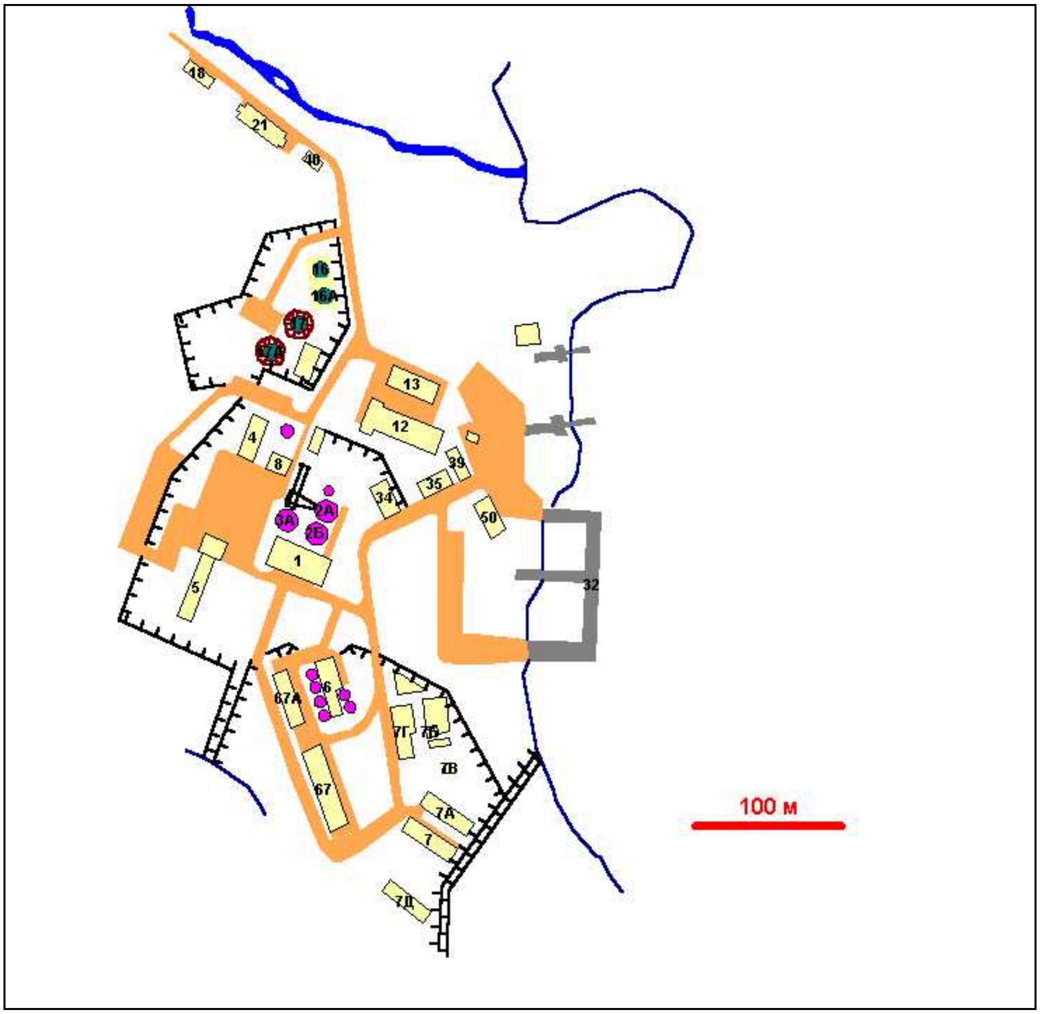

Figure 2.4. Scheme of CSE in Andreeva Bay

The CSE consists of the following buildings and installations (see Figure 2.4).

SFA Repository (installation n. 5)

The repository was put into operation in two stages (in 1962 and 1973) and was designed to accept and store SF. The construction is solid rectangular reinforced concrete pools coated inside with carbon steel 3 mm thick with a polymer coating. The pools are each 1000 m^3 in volume, and have a common transport corridor. When stored, packages were arranged on chain suspensions fastened with holders. In keeping with the design, the protective water layer from the top of the active SFA part to the surface water plane is at least four meters. The repository dimensions are 72×15 m. In November 1982, a drop of water level in one pool occurred. The pool unloading operations started in June 1983. Repair work was completed by January 1984. The second stage of the affected repository unloading was performed in 1989. At this stage, the whole SF stored within the building was unloaded. However, some amount of SF sediment is still located within the repository.

The building's technical state is considered as critical:

Supporting systems are inoperable;

One pool has cracks;

There are roof leakages;

Since the construction (in 1962) no major repair has been performed; and

The decontamination center is inoperable.

The radiation situation within the building 5 is extremely dangerous. Irradiation levels in the technological room (from the direction of the transport corridor) reach 3-6 mSv/h. Note that the maximum value of gamma-DR reaches 17 mSv/h or 1.7 R/h in this area.

The beta-contamination at some spots increases up to 48000 particles/cm^{2}min.

Blocks of SF Dry Storage (DSB, installations 2A, 2B, 3A).

The repository was built in 1965 and designed to accept and store LRW until their processing in a special building of water decontamination. The repository was never used, as designed. The construction is deepened solid reinforced concrete tanks, 1000 m^3 in volume each, coated with carbon steel. After the accident in installation n.5, described above, the tanks of installations 2A, 2B and 3A were re-equipped to store SFA packages in dry conditions. Within these tanks storage cells made of metal tubes were arranged. The inter-tube space was filled with concrete. At present, about 3000 packages with SF are stored within these repositories. In addition, 52 old-fashioned transportation casks containing SF are also stored at DSB.

SF is stored in special packages placed in the repository cells plugged with metal-concrete plugs and covered with a flooring.

Above the blocks 2A and 2B removable overlapping is arranged, though because of its lack of tightness, atmospheric precipitation reaches the surface of the SF blocks. The block 3A has no overlapping and is only covered with concrete plates. Thus, atmospheric precipitation reaches the repositories under consideration (the water activity measured in 2000 in some cells made up 10^{-2} Ci/l). The special-purpose ventilation system is inoperable. A major repair of the whole installation is required.

To store SRW the following are used:

repositories 1-7;

three open-air sites; and

additional repositories – two tanks of the LRW repository.

The integral volume of SRW stored at the CSE in Andreeva Bay is estimated as 6000 m^3.

To store LRW four tanks located in the LRW repository are used. The tanks are fully deepened, made of concrete, coated inside with stainless steel and are 400 m^3 in volume each. The integral volume of LRW stored at the CSE makes up ~1400 m^3.

The design operation time of the LRW-storage tanks has elapsed. Three tanks have leaks. A part of LRW is stored in the cellar. No data on the chemical composition of stored LRW is available. The radiation situation within installation n. 6 as well as in the tank area is considered as "normal" (gamma dose rate does not exceed 2 μSv/h).

Because of the depressurization of many buildings and installations *a part of CSE site* is contaminated. The former SF repository (installation 5) is the principal contamination source. After leaks of contaminated water out of the repository in 1982 through 1984, most of radionuclides was absorbed in the ground below the repository and washed out with ground waters and surface waters (partly, into the bay). As the result, the area close to the installation 5 and along a stream flowing under the construction became contaminated. The greatest ground contamination was recorded along the stream (~10^7 Bq/kg in ^{137}Cs and ~10^6 Bq/kg in ^{90}Sr). In the tidal zone, ground contamination was considerably less. Dose rates along the stream made up 200-250 μSv/h on average and reached 500 μSv/h at the most.

As a consequence of the above-described events, a part of the bay area adjacent to the stream was also contaminated. The contamination of bottom sediments at the stream mouth (20 m to 30 m from the coast) made up 200-300 Bq/kg for ^{137}Cs. At the same time, no radionuclide concentration above 100 Bq/m^3 ($3 \cdot 10^{-12}$ Ci/kg) was recorded in marine waters. By this is meant that the water area was contaminated far below the MAC.

To remove waters of the stream out of the installation n. 5, a special drainage ditch was built in 1999. As the result, the flow of contaminated water into the bay decreased radically, which improved the radioecological situation of the whole area.

The site of SRW storage represents another important contamination source of the territory under consideration. At some spots in the SRW site and around it, the ground contamination makes up 10^6 - 10^7 Bq/kg for ^{137}Cs and 10^5 - 10^6 Bq/kg for ^{90}Sr. From this it follows that some structures of the SRW site contaminated a part of the SRW site because of depressurization.

Thus, as a consequence of both normal and off-normal operation of CSE installations, radionuclides reached the soil at some spots and, thus created new sources of radioactive contamination requiring localization and elimination. Radiological investigations performed in 1998-1999 by a number of Russian institutions confirm the fact that the CSE site, its buildings and installations are rather hazardous.

The situation gravity results from the considerable amounts of SF and RW stored within the site under unsatisfactory conditions. The SF repository is the most hazardous construction, since its integral activity makes up 10^7 Ci, according to estimations. From the very outset, a considerable part of SF claddings stored in DSB was depressurized; as a result of long-term storage under unsatisfactory conditions, these claddings have collapsed.

Because about 10 t of mud containing fallen particles of SF with the integral activity of $\sim 4 \cdot 10^3$ Ci are located on the bottom of the pools, the installation 5 is in a critical state.

The present-day situation in CSE is further complicated by the presence of contaminated areas within its site. First of all, the area to the south of the installation 5 and along the stream up to the coastline is worthy of consideration. Here elevated radionuclide concentrations in the ground and high gamma dose rate values resulting from leaks of important amounts of radioactive waters out of a pool in installation 5 are recorded. There are strong grounds for believing that the contaminated water has reached a considerable depth below the installation itself and also adjacent areas. Elevated radionuclide concentrations are also recorded at some spots of the SRW site (around repositories including open-air storage sites) and at the permanent technological berth.

Based on the above brief description and using the available radioecological data, one can reach the following conclusions:

- as the result of long-term normal and off-normal operation of CES in Andreeva Bay elevated concentrations of technogenic radionuclides in the environment media and high levels of external gamma-irradiation on site are recorded. At individual spots the environmental contamination (soil, ground below the soil, water flows) exceeds by many times (up to 1000) the MAC in force in Russia;
- individual installations (in particular, SRW repository and open-air sites of SRW storage) still contaminate the environment because of their depressurization, resulting in immediate contact of atmospheric precipitation with SRW;
- the installation 5 is especially hazardous because of its emergency state (cracks in the pool boarding, contaminated mud on the pool bottom);
- considerable LRW amounts (over 700 m^3) also represent a real source of environmental contamination. They are stored in tanks that are in an unsatisfactory state; and
- as a consequence of the CSE site radioactive contamination, the radioactivity of bottom sediments in the littoral zone increases also.

2.4.2. CSE in Gremikha Settlement (Branch №2 of SFUE "SevRAO")

The CSE of Gremikha-settlement is located at Iokagan'skiy Bay coast (see Figure 2.5). The site contains one to three story buildings and industrial-type installations. The CSE site area makes up ~150 000 m^2.

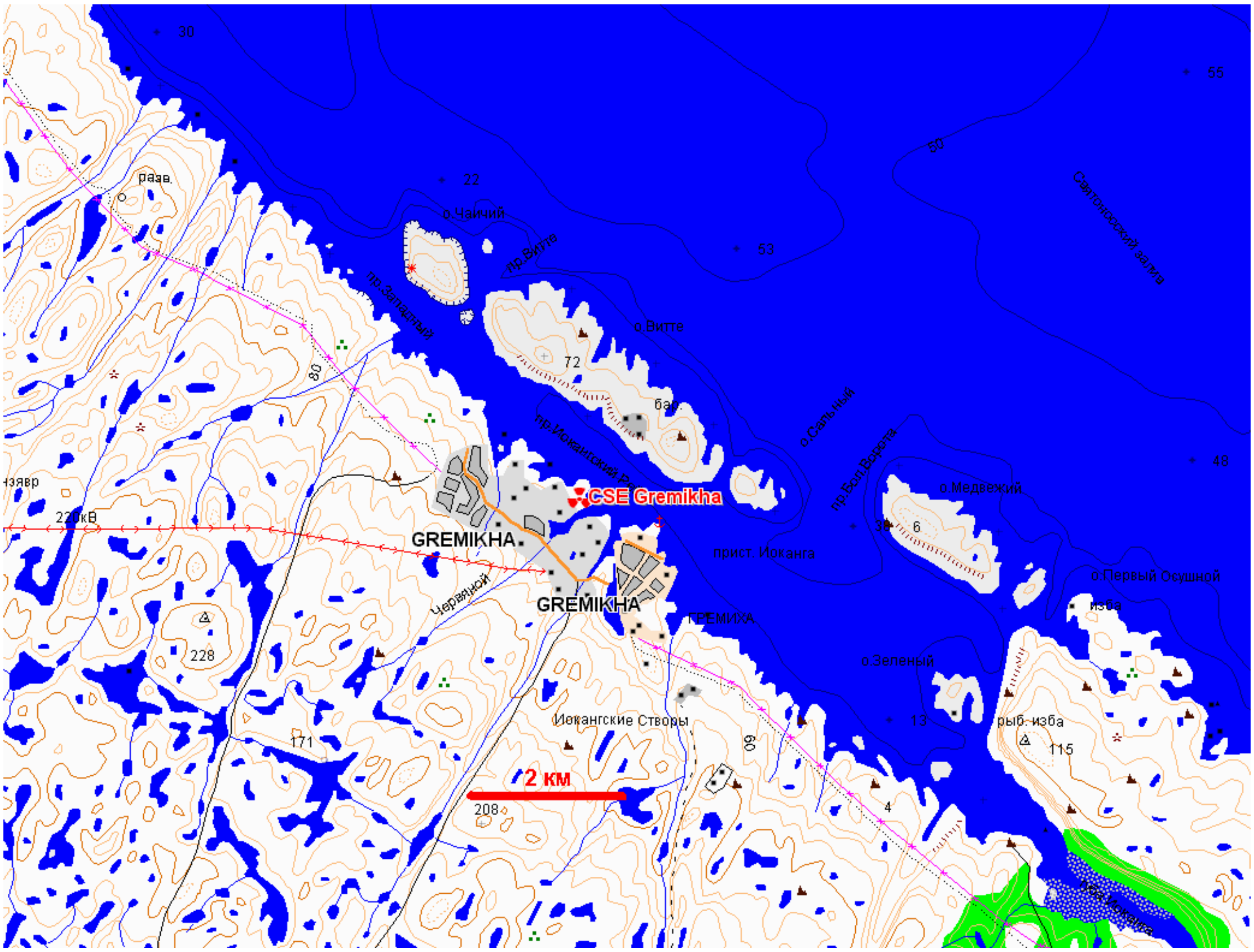

Figure 2.5. Map of the Neighborhood of CSE in Gremikha

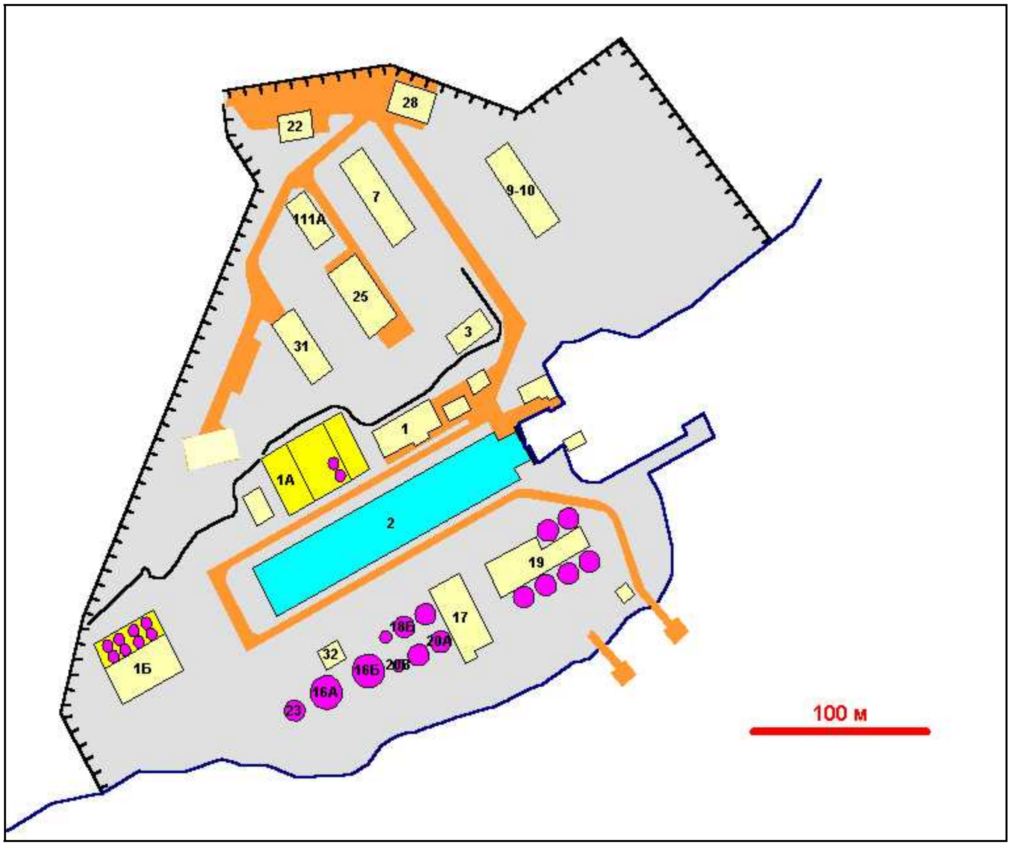

Figure 2.6. Scheme of CSE in Gremihka

The CSE includes the following principal buildings and installations (Figure 2.6):

<u>*SF Repository (Installation 1)*</u> for the first-generation NS with PWR. The installation was built in 1962 and consists of four independent pools and a common technologic room. Each pool is a concrete basin coated with carbon steel 5 mm thick. Because of one pool depressurization, repository operation was forbidden after 1986. At present, three pools are almost emptied. SFA are stored in five-place packages located in the pool sumps. There are 95 SFA in the water medium of pool 2 (including 18 SFA located on the pool bottom). All SFA have different types of mechanical failures and are considered “defective”. This means that they are not to be transported to a nuclear fuel regenerating plant.

The state of the repository construction is unsatisfactory:

three pools have leaks;

the state of coating of pool 2 (containing SF) is critical because of heavy corrosion; and
no up-to-date transport and technological equipment is available to reload SF.

The radiation situation within the repository is characterized as “dangerous”. The level of gamma dose rate in the repository room makes up 50-100 μSv/h; while in some areas it reaches 1000-2000 μSv/h. The beta-contamination of the room equals 250 Bq·km^2 min on average and reaches a maximum of 2080 Bq·km^2 min.

<u>*Building to Reload NS*</u> (Installation 1A) with Liquid-Metal Coolant (LMC) was built in 1989. It consists of three sections, a one-story building of so-called “special production” and of two four-story auxiliary-purpose buildings united into a single construction. The installation was mainly designed for initial storage of Spent Extractable Parts (SEP) of LMC with forced cooling, storage and setting-up procedures for reloading equipment, equipment decontamination, and CPS assembly, repair and testing. The special technologic equipment (including the SEP repository as well as different maintenance systems) is operable.

<u>*SEP Repository of NS with LMC*</u>. (installation 1B) was built in 1961 and reconstructed in 1988. The construction is designed to:

accept and store SEP for a long-time;
accept and cool inert gases from NS, and supply NS with inert gases.

At present six SEP are stored within the repository. The construction is a one-story building 30.5×25.3 m in area and 4.1 m in height. The building has eight storage facilities for long-term storage of SEP. SEP are placed into «frozen» coolant, which is stored in a special storage tank. Such a storage mode is normal; it provides the best radionuclide localization and, thus, ensures nuclear, radiation and radioecological safety.

The state of building construction is unsatisfactory. There are cracks in walls and the basement and leaks in the roof; and the power supply system is inoperable. Until making decision on SEP removal from CSE, the repository should be used in keeping with its initial design. The radiation situation in the repository is normal, i.e., 0.3-0.8 μSv/h.

SRW Temporary Storage Site was designed to store SRW temporarily but is used to store SRW and SF in old-type containers. It is a concrete site 300 m^2 (20.0×15.0 m) in area walled on three sides by a 3.0 m high concrete block wall. In addition, there is a barbed wire around the site at a distance of 5-10 m from the wall. The SRW site is located on a hill.

SRW amount stored within the site makes up ~500 m^3. There are: equipment of the primary circuit, traps with ion-exchange resins, individual protectants, et al., as well as other large-sized equipment (two motor-cars and autocrane fragments). SRW are stored mainly in standard steel containers 1×1×1 m; some of these containers are depressurized.

The conditions of SRW storage within the site do not meet the requirements of standard acts to store SF and SRW because of the following reasons:

- no efficient fence (protecting the site from unauthorized access) is available;
- the site has no awning against atmospheric precipitation;
- there is no special mastic covering; and
- no drainage system is available.

The SRW site represents a source of elevated background radiation. Containers with SF and ion exchange resin traps are the principal sources of elevated gamma-irradiation levels.

Irradiation levels at the site are rather high: at the site entrance the gamma dose rate reaches 3000 μSv/h (0.3 R/h), beyond its bounds it increases up to 20-40 μSv/h.

RW Repository (Installation 19) was built in 1966 and was designed for long-term storage of radioactive concentrates after LRW processing in the special building of water decontamination. However, the repository was never used in keeping with its design. At present, SRW are temporarily stored within the facility, the state of which is considered as “satisfactory”. Irradiation levels in the repository rooms close to SRW containers are rather high: maximum gamma dose rates reach 1200 μSv/h (0.12 R/h).

LRW repository (installations 20A and 20B) was built in 1962 to store temporarily LRW of low and medium activity. The installations cotain solid deepened reinforced concrete tanks coated with steel. Altogether there are 11 tanks, with volumes varying from 100 m^3 to 500 m^3. On the outer surfaces, special reinforced hydro-insulation is placed.

The following systems are unavailable in both installations:

- tank leakage control system;
- tank level control system; and
- sampling system.

Irradiation levels above the tanks make up 0.5-3.5 μSv/h.

The open-air site of SRW temporary storage is the main contamination source within the *CSE territory*. From the point of view of environmental contamination the situation gravity increases further because, in addition to SRW, SF is also stored (within old-type containers) at the site.

The highest ground contamination is found on the outer side of the concrete wall. Here high levels of γ-irradiation (from 500 μSv/h to 800 μSv/h) are recorded. This indicates a partial radionuclide migration out of the site via precipitation leaking under the concrete wall.

Supplementary measurements of the ground activity close to the shoreline revealed no contamination of the marine medium from the SRW site.

The LRW repository is another source of the CSE territory contamination. In its area there are ground spots with specific activity of $\sim 2.5 \cdot 10^4$ Bq/kg.

The SF repository represents the principal source of the CSE radioecological risk. Taking into account the rate of tank coating corrosion (about 0.1 mm per year), its depressurization is possible within a few years. As the result, contaminated waters will flow out of the tank № 2. According to the data of 1998, the specific activity of water in tank 2 makes up $4 \cdot 10^5$ Bq/kg. The tank sumps store 106 SFA, of which most have different mechanical failures and are considered defective SFA. There is also defective SFA on the tank № 2 bottom.

The open-air site of SRW temporary storage is a further (rather serious) potential source of environmental contamination. In addition to important SRW amounts (~500 m^3), 114 old-type containers charged with SF packages and exposed to atmospheric precipitation are stored at the site. The state of SRW and SF containers is unsatisfactory. Many SRW containers are depressurized and have through holes. Some SF containers are partly filled with water.

2.5. Changes in the Radioecological Situation within Nikolsky Mouth Water Area when Performing Nuclear Submarine Dismantling and Repair Operations

Over a period of years, the radiation situation within Nikolsky Mouth water area has varied more than once. In the course of the period of nuclear submarine repair (before 1990) technogenic radionuclides were released directly to the marine environment. As a result, concentrations of ^{60}Co, ^{90}Sr and ^{137}Cs in the water space of Nikolsky Mouth exceeded those in the open waters of the White Sea by a factor of two through eight, and made up 0,001 to 0,002 of MAC practically the whole time [2.11]. After the onset (in 1991) of large-scale nuclear submarine dismantling operations at the enterprises of the Russian State Center of Nuclear Shipbuilding, the situation had changed for the better. However, the specific activity of both ^{90}Sr and ^{137}Cs still remains above the background level (by a factor of 1,5 to 2), whereas that of ^{60}Co is comparable to the radiation background value (below 0,001 of MAC), see Figure 2.7, Table 2.17.

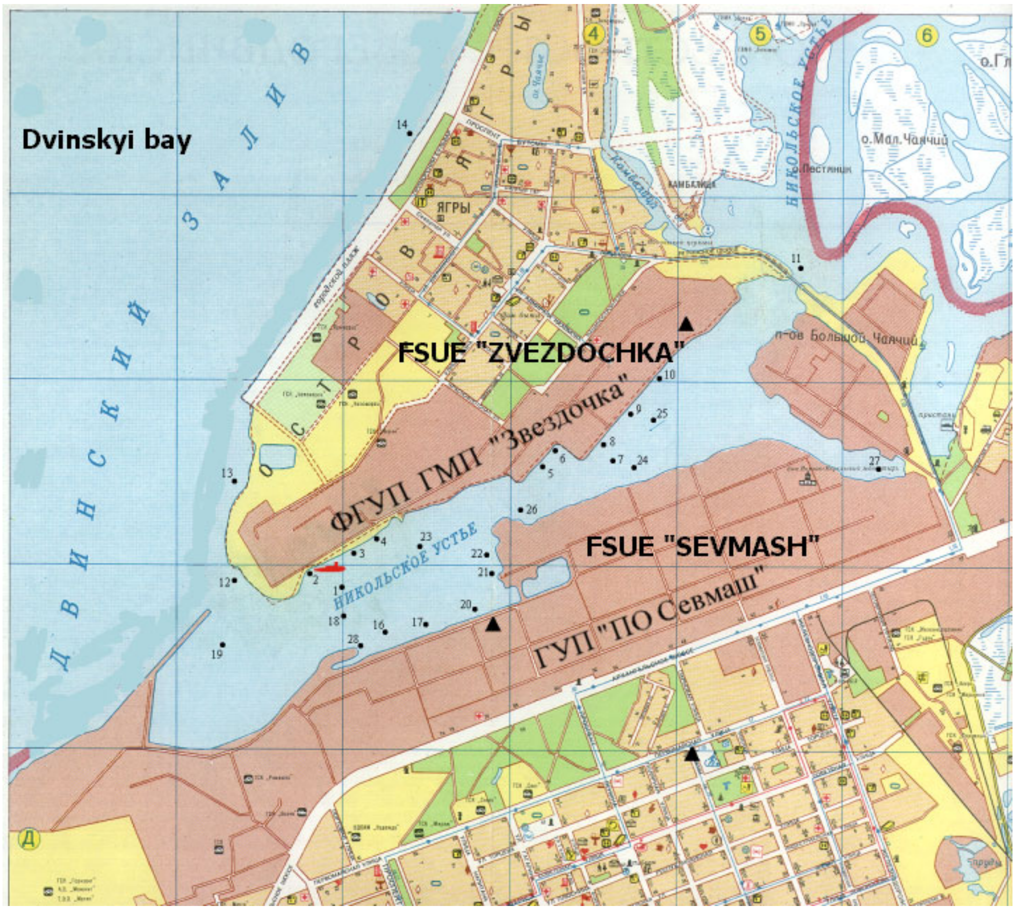

Figure 2.7. Points of Bottom Sediment Sampling within Nikolsky Mouth & Dvinskoy Bay (•), of Aerosols & Surface Deposition Sampling (▲) and the Berthing of a Nuclear Submarine with Damaged Power Reactor Facility in 1965( ).

Table 2.17 Specific Activity of Technogenic Radionuclides in Waters of Nikolsky Mouth as Compared to Water Areas with Background Concentrations, Bq/m^3

Year	Sampling Location	Radionuclide		
		^{60}Co	^{90}Sr	^{137}Cs
1989 Nikolsky Mouth	Outlet from Nikolsky Mouth	7.7±2.2	10.0±3.0	14±3
	Deep-water quay	1.0±0.2	8.0±2.7	46±12
	Deep-water quay	1.7±0.3	7.5±2.2	44±11
	Fuel unloading quay	4.0±1.0	6.4±2.0	50±14
1998 Nikolsky Mouth	Pier of the deep-water quay	< 0.8	6.0±2.0	-
	Fuel unloading quay	< 0.2	11.0±3.3	-

Year	Sampling Location	Radionuclide		
		^{60}Co	^{90}Sr	^{137}Cs
1999 Nikolsky Mouth	Deep-water quay	< 0.2	6.0±2.0	-
	Harbor	< 0.2	6.0±2.0	8.6±2.6
	Water space close to the bridge	< 0.2	8.0±2.7	-
	Point № 16 (September 1st 1999)	< 0.2	6.0±2.0	-
	Point № 19 (September 1st 1999)	< 0.2	6.0±2.0	8.3±2.8
	Point № 28 (September 1st 1999)	< 0.2	8.0±2.7	-
2000 Nikolsky Mouth. p. № 29– inlet, т. № 30– outlet	Point № 29 (August 15th 2000)	< 0.2	9.2±3.1	-
	Point № 29 (September 12th 2000)	< 0.8	5.4±1.8	-
	Point № 29 (October 10th 2000)	< 0.8	8.4±2.8	-
	Point № 30 (August 15th 2000)	< 0.9	6.8±2.2	9.4±3.2
	Point № 30 (September 12th 2000)	< 0.9	7.2±2.4	-
	Point № 30 (October 24th 2000)	< 0.9	5.6±1.8	-
Background Dvinskoy Bay White Sea	Uima-settlement (August 30th 1999)	< 0.2	7.9±2.6	-
	Uima-settlement (October 30th 2000)	< 1.0	8.7±2.9	-
	Bolshaya Pir'ja Bay	< 0.7	7.6±2.5	-
	Olenitsa Bay	< 0.7	5.4±1.7	8.8±2.9
	Open Sea	< 0.7	1.5±0.4	2.4±0.6
Background * 100-km radius area around SUE Sevmash PA	Northern Dvina (Solombala-settlement)	< 0.2	8.5±2.6	-
	Onega-river (Porog-village), 1999	< 0.2	3.9±1.7	-
Background Territory of Russia 1999	European Part average (rivers)*	< 0.2	6.2±2.1	-
	Asiatic Part average (rivers)**	< 0.2	6.1±2.1	-
	Far East region average **			
	- rivers;	< 0.2	3.0±1.2	4.8±2.0
	- lakes;	< 0.2	27.0±8.2	43.2±12.2
	- seas.	< 0.2	1.7±0.6	2.7±1.1

Comments:* data of [2.8], ** data of [2.6].

An analysis of the current technologies used to carry out nuclear submarine repair and dismantling operations demonstrates that both the unloading of spent nuclear fuel and radioactive waste handling represent the main causes of Nikolsky Mouth radioactive contamination. In the course of the above-mentioned operations LRW and SRW are being created constantly; therefore, when working in "afloat" conditions, RW collection is rather difficult. Thus, the possibility that some RW amount reaches the water space must not be ruled out. (Table 2.18 and 2.19 [2.1]).

Table 2.18 Integral Volumes of Liquid Radioactive Wastes Being Created when Utilizing One Nuclear Submarine, m^3

Radioactive Waste Type	**Nuclear Submarine Class**			**Specific activity, Bq/l**
	"Delta"	**"Oscar"**	**"Typhoon"**	
Coolant of the primary circuit and process waters of the third circuit	80±2	95±2	95±2	$1\text{-}5 \cdot 10^{3\text{-}7}$
Decontaminating solutions of the reactor compartment and technological fittings	4±0.5	20±1	20±1	$1\text{-}5 \cdot 10^{2\text{-}4}$
Process waters of contaminated water tanks and holds	2±0.5	10±1	10±1	$1\text{-}5 \cdot 10^{2\text{-}4}$
Process waters of biological protection tanks	170±3	280±5	350±5	$1\text{-}5 \cdot 10^{2\text{-}4}$

Comments: LRW contain: ^{54}Mn - 3-5%, ^{60}Co – 5-10%, ^{90}Sr – 10-12%, ^{134}Cs – 5-10%, ^{137}Cs – 50-70%.

Table 2.19 Integral Volume of Solid Radioactive Wastes Being Created when Utilizing One Nuclear Submarine, m^3

Radioactive Waste Type	**Nuclear submarine class**			**Density, β/sm^2· min**	**Specific activity, Bq/kg**
	"Delta"	**"Oscar"**	**"Typhoon"**		
Power reactor facility equipment	8±1	10±1	10±1	> 50	$> 7 \cdot 10^4$
Insulating coatings	2±0,5	5±0,5	5±0,5	< 50	$> 7 \cdot 10^4$
Auxiliary materials	20±2	20±2	20±2	< 50	$> 7 \cdot 10^4$

Comments: SRW contain: ^{54}Mn – 3-5%, ^{60}Co – 10-15%, ^{90}Sr – 10-12%, ^{134}Cs-134 – 3-5%, ^{137}Cs – 60-70%.

As a rule, unauthorized amounts of LRW disposed into marine waters are rather small (one to dozens of liters) and do not constitute a radioecological threat due to the process of turbulent diffusion resulting in a decrease of the radionuclide concentration to admissible values in the course of few hours. These are solid radioactive residues (a component of LRW) and small-sized SRW particles that may create a contamination problem. Occasionally reaching the seabed, these particles become non-removable and accumulate. Both the investigations of [2.10] and the data from monitoring in Nikolsky Mouth prove that such particles represent a source of long-duration radioactive contamination of the marine environment within areas of nuclear submarine handling (see Figure 2.4, Tables 2.20 and 2.21).

Table 2.20 Specific Activity of Radionuclides in Bottom Sediments of Nikolsky Mouth within the Site of FSUE "SMBE “Zvezdochka” and in Dvinskoy Bay, Bq/kg

Point №	Radionuclide	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1*	Specific activity	535	510	600	667	518	522	654	478	513	580	470	560
	Cs-137	27	29	27	21	14	23	14	17	8	18	10	12
	Co-60	20	bd	bd	bd	bd	bd	-	bd	bd	2	bd	bd
2*	Specific activity	320	580	690	420	503	555	613	637	526	510	350	540
	Cs-137	10	39	59	45	22	41	28	40	30	30	12	12
	Co-60	bd	15	19	bd	bd	bd	3	3	6	4	2	3
3*	Specific activity	630	750	704	772	725	633	614	624	626	670	460	650
	Cs-137	60	61	73	51	47	25	29	52	25	47	19	42
	Co-60	14	bd	24	bd	82	14	3	4	bd	25	bd	bd
4*	Specific activity	7104	530	540	-	613	604	566	558	731	460	580	590
	Cs-137	26	23	25	-	46	24	24	43	34	9	24	22
	Co-60		bd	bd	-	154	10	3	3	7	1	bd	3
5**	Specific activity	470	660	615	504	652	617	455	522	414	570	540	560
	Cs-137	25	40	32	62	29	30	15	30	22	33	27	30
	Co-60	21	18	bd	bd	bd	8	3	2	bd	2	2	bd
6**	Specific activity	570	500	493	490	570	607	574	687	539	620	540	560
	Cs-137	52	56	45	48	48	21	32	32	22	26	44	37
	Co-60	50	25	47	15	19	33	4	3	1	1	3	1
7***	Specific activity	610	444	600	450	558	-	589	430	422	-	520	440
	Cs-137	32	15	30	15	5	-	8	9	10	-	11	5
	Co-60	21	bd	12	bd	bd	-	1	1	bd	-	bd	1
8***	Specific activity	760	540	800	558	622	555	574	478	574	670	530	580
	Cs-137	56	33	60	42	22	89	21	25	34	37	16	38
	Co-60	91	14	23	12	bd	6	2	1	3	3	bd	4
9***	Specific activity	-	-	-	-	-	629	535	640	626	700	520	600
	Cs-137	-	-	-	-	-	36	18	29	22	46	11	19

Point №	Radionuclide	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	Co-60	-	-	-	-	-	bd	bd	bd	bd	6	bd	bd
10***	Specific activity	635	780	630	590	422	370	650	625	580	615	540	690
	Cs-137	53	81	115	35	17	41	24	33	31	28	21	32
	Co-60	bd	bd	330	14	bd	bd	10	3	bd	1	bd	3
11****	Specific activity	520	620	359	458	-	330	410	482	473	-	250	460
	Cs-137	30	45	bd	27	-	bd	13	15	12	-	1	10
	Co-60	16	58	bd	bd	-	bd	bd	3	bd	-	bd	bd
12****	Specific activity	370	210	460	445	288	518	417	410	-	320	350	230
	Cs-137	14	5	7	7	38	2	2	29	-	1	3	6
	Co-60	bd	bd	bd	bd	bd	bd	-	bd	-	bd	bd	bd
13****	Specific activity	-	-	-	500	-	-	378	-	-	300	330	370
	Cs-137	-	-	-	7	-	-	7	-	-	1	1	2
	Co-60	-	-	-	bd	-	-	-	-	-	bd	bd	bd
14****	Specific activity	330	240	320	230	302	346	304	367	343	270	375	250
	Cs-137	7	bd	bd	bd	bd	2	bd	bd	2	2	1	2
	Co-60	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd
15*****	Specific activity	-	-	-	-	-	-	-	-	-	-	-	-
	Cs-137	10	-	-	-	-	12	11	9	-	11	8	9
	Co-60	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd

Comments: bd – below detection limit, * quay of spent fuel unloading, LRW & SRW receiving and transmitting, ** deep-water quay (radioactive waste handling operations), *** nuclear submarine waterborne storage after the decommissioning, **** p. 11 - Nikolsky Mouth inlet; p.12 – Nikolsky Mouth outlet and Dvinskoy Bay inlet; pp. 13 and 14 – Dvinskoy Bay (town beach), background values, ***** Dvinskoy Bay of the White Sea, 15 km from Severodvinsk-town (averaged data over 10 points [2.8]). The error of measurements makes up 30%.

Table 2.21. Specific Activity of Radionuclides in Bottom Sediments of Nikolsky Mouth within the Site of SUE "Sevmash PA", Bq/kg

Point №	Radionuclide	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
16	Specific activity	814	777	666	629	629	603	527	592	655	666
	Cs-137	16	-	11	-	10	4	18	12	9	5
	Co-60	bd	-	bd	-	bd	bd	bd	bd	-	-
	Sr-90	2	-	bd	-	4	1	bd	bd	bd	bd
	Ce-144	-	-	3	-	6	6	-	-	-	-
17	Specific activity	703	740	666	666	666	629	518	810	605	803
	Cs-137	14	-	13	20	12	3	4	18	28	7
	Co-60	4	-	bd	bd	3	bd	-	bd	-	-
	Sr-90	2	-	bd	bd	11	1	4	1	3	bd
	Ce-144	-	-	2	6	bd	-	-	-	-	-
18	Specific activity	481	851	370	592	370	629	481	-	-	665
	Cs-137	12	-	21	3	5	16	-	-	-	13
	Co-60	bd	-	bd	bd	bd	bd	2	-	-	-
	Sr-90	0,3	-	bd	bd	bd	1	bd	-	-	1
	Ce-144	-	-	7	bd	2	5	1	-	-	-
19*	Specific activity	777	777	666	629	629	640	703	742	723	-
	Cs-137	9	-	bd	13	58	4	18	30	35	-
	Co-60	bd	-	bd	bd	bd	bd	bd	bd	-	-
	Sr-90	0,4	-	bd	1	1	1	bd	bd	bd	-
	Ce-144	-	-	4	bd	5	16	8	-	-	-
20	Specific activity	666	925	666	703	703	629	653	748	-	703
	Cs-137	-	-	20	16	1	11	12	14	-	9
	Co-60	-	-	2	bd	bd	bd	10	bd	-	-
	Sr-90	-	-	bd	bd	bd	1	bd	bd	-	bd
	Ce-144	-	-	10	22	4	6	-	-	-	-
21	Specific activity	555	444	666	777	-	740	539	-	-	666
	Cs-137	-	-	9	-	-	27	2	-	-	-
	Co-60	-	-	1	-	-	bd	5	-	-	-
	Sr-90	-	-	bd	-	-	bd	bd	-	-	3
	Ce-144	-	-	2	-	-	5	bd	-	-	-
22	Specific activity	666	814	-	703	740	777	640	710	629	745
	Cs-137	-	-	-	5	-	15	13	16	11	26
	Co-60	-	-	-	bd	-	bd	bd	bd	-	-
	Sr-90	-	-	-	bd	-	1	bd	1	bd	bd
	Ce-144	-	-	-	4	-	9	5	-	-	-
23	Specific activity	666	-	740	703	703	666	703	-	683	684
	Cs-137	-	-	13	13	3	bd	4	-	10	17
	Co-60	-	-	1	bd	bd	bd	bd	-	bd	-
	Sr-90	-	-	-	bd	bd	bd	bd	-	bd	bd
	Ce-144	-	-	11	6	2	24	6	-	-	-
24	Specific activity	629	-	777	518	484	666	684	703	-	700
	Cs-137	-	-	14	12	11	27	11	11	-	6
	Co-60	-	-	bd	bd	bd	16	1	bd	-	-
	Sr-90	-	-	bd	bd	bd	5	bd	1	-	bd

Point №	Radionuclide	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	Ce-144	-	-	3	bd	4	5	5	-	-	-
25	Specific activity	630	-	-	518	666	-	481	629	-	592
	Cs-137	-	-	-	59	1	-	8	-	-	3
	Co-60	-	-	-	bd	bd	-	bd	1	-	-
	Sr-90	-	-	-	4	bd	-	bd	4	-	bd
	Ce-144	-	-	-	3	5	-	1	-	-	-
26	Specific activity	740	-	814	629	-	703	740	610	666	670
	Cs-137	-	-	27	15	-	-	12	23	14	-
	Co-60	-	-	bd	bd	-	-	bd	bd	bd	-
	Sr-90	-	-	bd	bd	-	-	bd	bd	bd	1
	Ce-144	-	-	6	3	-	-	4	-	-	-
27	Specific activity	-	-	-	-	-	-	-	632	592	814
	Cs-137	-	-	-	-	-	-	-	40	21	37
	Co-60	-	-	-	-	-	-	-	2	bd	-
	Sr-90	-	-	-	-	-	-	-	2	1	1
28	Specific activity	-	-	-	-	-	-	-	720	666	814
	Cs-137	-	-	-	-	-	-	-	30	14	48
	Co-60	-	-	-	-	-	-	-	bd	bd	-
	Sr-90	-	-	-	-	-	-	-	bd	bd	bd

Comments: * Nikolsky Mouth inlet.

Thus, as follows from the data of Table 2.20, in areas of preparing NS utilization operations and RW handling operations (see Figure 2.7, pp. 1-10) the specific ^{137}Cs activity of bottom sediments exceeds the background level by a factor of two to nine on average. In individual years, the excess reaches 20 to 130 times (e.g., p. 10 in 1990 and 1991). An increase by a factor of 1.3 of specific β-activity of bottom sediments in point 10 in 1990 indicates the presence of not only ^{137}Cs and ^{60}Co radionuclides but also of ^{90}Sr. In the considered case, ^{90}Sr concentrations might have varied within the range of 50 through 150 Bq/kg.

On the opposite side of the Nikolsky Mouth the concentration of technogenic radionuclides in bottom sediments is slightly less (Figure 2.7, Table 2.21). There, sampling found: mainly ^{137}Cs, a slight excess of ^{60}Co and ^{144}Ce, and ~ background concentrations of ^{90}Sr. In keeping with [2.11], their concentrations did not exceed 0.005-0.02 of MAC; the only exceptions were recorded in 1990 and 1991 in p. 10 (Table 20) when these values reached 0.2-0.9 of MAC. In previous years (in particular, in 1975 through 1978, pp. 16 and 17) the contamination of bottom sediments by ^{137}Cs reached twice MAC at the most (5200 Bq/kg [2.11]) in the course of work with contaminated floating ships.

To survey radionuclide transfer beyond the boundaries of Nikolsky Mouth, the North Department of Hydrometeorological Service (NDHS) of Roshydromet has been taking samples of bottom sediments in Dvinskoy Bay of the White Sea (close to Severodvinsk-town) since 1975. The radionuclide analysis has been performed by RPA "Typhoon" (Obninsk-town). Based on long-term observations of ^{137}Cs concentration (Table 2.19, p. 15) and their minor average levels (10±2 Bq/kg), RPA "Typhoon" considers the recorded values as global radiation background concentrations. Simultaneously, the activities of the concerned enterprises in Severodvinsk are judged as unaffecting the concentrations of technogenic radionuclides in Dvinskoy Bay [2.8].

Such a conclusion is quite justified from the point of view of the global radioactive contamination of the Arctic Seas, especially as the concentrations of artificial radionuclides in the White Sea waters slightly exceed those in other water basins of the concerned region. When considering bottom sediments, ^{137}Cs-concentrations recorded in the White Sea are comparable to (or less than) the corresponding concentrations in the Norwegian Sea, Greenland Sea or Kara Sea (Table 2.22 [2.12, 2.13]).

Table 2.22. Concentrations of Artificial Radionuclides in Waters, Bottom Sediments and Biota of the Arctic Seas in 1991 through 1998

Sea	**Water, Bq/m^3**		**Bottom Sediments, Bq/kg**		**Fish, Bq/kg**	
	Sr-90	**Cs-137**	**Sr-90**	**Cs-137**	**Sr-90**	**Cs-137**
North Sea	4.2±1.6	6.3±2.9	-	6±3	-	0.2±0.1
Norwegian Sea	3.0±0.8	5.2±2.8	3.5±1.3	26±18	-	0.5±0.2
Greenland Sea	2.0±0.2	3.4±1.0	-	13±5	-	0.3±0.1
Barents Sea	4.0±1.0	5.8±1.5	0.3±0.2	8±3	0.02±0.01	0.8±0.6
White Sea	6.8±2.5*	10.0±2.0*	-	10±2**	0.14±0.04***	0.6±0.2***

Kara Sea	5.1±2.0	6.2±1.6	1.5±1.3	15±6	0.03±0.01	0.6±0.5
Laptev Sea	5.2±1.5	5.0±4.0	-	-	-	-
Chukchi Sea	2.1±1.0	2.5±0.6	-	-	-	-
Bering Sea	1.8±0.8	1.6±0.5	-	-	-	-

Comments: * elevated concentrations result from the transfer of water masses contaminated by radioactive astes of SF reprocessing plant in Sellafield (former Windscale), Great Britain [2.13]. ** Dvinskoy Bay, *** seal. Values of specific activity are given: for bottom sediments per unit of dry weight, for biota per unit of raw weight.

However, an analysis of the data obtained recently by specialists of both NDHS of Roshydromet and SRA "Typhoon" (with consideration for sampling points) allows the opposite conclusion, which is also confirmed by the results of some independent investigations (Figure 2.8, Table 2.23 [2.8]).

Figure 2.8. Location of Bottom Sediment Sampling Points in Dvinskoy Bay of the White Sea

Table 2.23. Concentration of ^{137}Cs in Bottom Sediments of Dvinskoy Bay 15 km from Severodvinsk in 1998 through 2000, Bq/kg (Dry Weight)

№ of Sampling point	October 13th 1998		October 16th 1999		August 22nd 2000	
	Depth, m	Activity	Depth, m	Activity	Depth, m	Activity
1*	10	24.7 ± 0.9	12	27.1 ± 1.7	11	16.4 ± 1.0
2	9	8.3 ± 0.7	12	6.8 ± 1.1	11	< 0.5
3*	12	5.6 ± 0.5	13	15.6 ± 2.0	13	12.5 ± 0.7
4	12	6.7 ± 0.6	14	< 1.3	12	4.3 ± 0.6
5*	11	16.8 ± 1.2	14	9.1 ± 0.8	12	5.5 ± 0.5
6*	13	9.3 ± 0.7	13	6.0 ± 0.7	13	6.4 ± 0.6
7	11	5.9 ± 0.4	14	2.3 ± 0.4	12	6.9 ± 0.6
8	8	5.8 ± 0.5	10	8.7 ± 1.0	9	2.3 ± 0.4
9	10	8.5 ± 0.7	10	2.2 ± 0.4	10	9.3 ± 0.6
10*	10	17.6 ± 0.8	12	< 0.6	12	21.5 ± 1.4

Comments: * local area with elevated ^{137}Cs concentration.

Taking into account that the points no. 13, 14 (Figure 2.7, Table 2.20) and no. 2, 4, 8, 9 (Figure 2.8, Table 2.23) of bottom sediment sampling are located far from the principal water currents out of Nikolsky Mouth, let us consider the results of measurements at these points as the background values. Thus, the background value makes up 5±2 Bq/kg. According to [2.14], ^{137}Cs concentrations within the adjacent to Severodvinsk-town water areas are equal to 4,2±1,5 Bq/kg in Nikolsky Arm, to 5.4±1.8 Bq/kg in the delta of the North Dvina and to 2.3±0.5 Bq/kg along the coast of Jagry-island.

At the same time, at the points 1, 10, 5, 6 and 3 located close to each other (Figure 2.8, Table 2.23), ^{137}Cs concentrations vary from 10 to 27 Bq/kg. Here a drop in values from 21±3 Bq/kg (points 1 and 10) to 10±3 Bq/kg (points 5, 6 and 3) is recorded. This indicates the direction of technogenic radionuclide transfer within the near-bottom sea-water layer from Nikolsky Mouth to Dvinskoy Bay, as follows: p.1 → p.5 → p.3. At a 15-km distance from Severodvinsk-town the width of the contaminated zone reaches 3 to 5 km; here a seabed depression plays the part of a local accumulator of the radioactive contamination. The change of ^{137}Cs-transfer pathway from northeast to north is explained by the presence of a local seabed height behind the points 6 and 7, which modifies the direction of near-bottom water mass transfer, as indicated.

The fact of the technogenic radionuclide transfer from Nikolsky Mouth in Dvinskoy Bay is also confirmed by the results of long-term observations within the near zone at p. 12 (Figure 2.7, Table 2.20) and p. 19 (Table 2.21) performed by specialists of SMBE “Zvezdochka” and SUE “Sevmach PA”. These points are situated at the Mouth outlet at a distance of 500 m to 1500 m from the considered enterprises, but from time to time ^{137}Cs concentrations at these points exceed the background values by a factor of two to eight. These events are concurrent with SF unloading operations and, correspondingly, with the radioactive contamination of the Mouth in the points 1 through 4 and 16 through 18.

At point 11 (Figure 2.7, Table 2.20) taken as a background one (the point is located 500 m from the enterprises against the current) elevated concentrations of technogenic radionuclides in bottom sediments were recorded. Thus, in 1990 ^{137}Cs concentration increased 9 times and that of ^{60}Co 60 times. Such a paradoxical phenomenon can be attributed to occasional LRW ingress from SMBE “Zvezdochka” into the sewerage system and sewage disposal plants of Severodvinsk-town which results in the contamination of Nikolsky Mouth inlet. In 1990, according to estimations of “Nevskgeologuia” specialists, the area contaminated at a level over 20 μR/h (3000 μR/h at the most) equaled 400 m^2. The specific activity of ^{54}Mn in the mud reached 2200 Bq/kg, of ^{60}Co – 81000 Bq/kg, and of ^{137}Cs – 3200 Bq/kg. Later on, unauthorized use of the mud by the local population for agricultural purposes contributed to further spreading of the radioactive contamination over the northern part of Jagry-island. As a result, the dose rate within homestead plots of Jagry-settlement increased up to 20-30 μR/h. Thanks to various decontamination operations, the average dose rate value was lowered to 10-15 μR/h (background values). In 1999, the maximum dose rate values made up 60-200 μR/h within the central part of the contaminated spot (5% of the initially contaminated area of 400 m^2). As a consequence, the concentrations of ^{60}Co decreased by a factor of 15 to 60 and those of ^{137}Cs by a factor of two to four in the bottom sediments of Nikolsky Mouth inlet (see p. 11, Figure 2.7, Table 2.20).

2.6. Issues of Ecological Rehabilitation of the Contaminated CSE Areas

The sites of SF and RW storage in Andreeva Bay and Gremikha settlement put into operation in the early 1960s should be considered the most hazardous from the standpoint of the environmental contamination risk.

Thus, underestimation of local geographical conditions, use of temporary repositories to store RW and SF lacking in reliable protective equipment, and imperfections in RW and SF storage techniques employed at the time resulted in unfavorable (in some areas dangerous) changes in the radioecological situation within the CSE of Andreeva Bay.

During the period of CSE operation its ground was contaminated, and some radionuclide amounts reached the water area of Bolshaya Lopatka Bay.

The contamination is mainly due to an accident that occurred in the SF repository in 1982 (installation № 5) and radionuclides washing out of open-air sites of SRW storage. As a result of the accident (outflow from a pool of SF storage), about 1000 Ci of radioactive substances reached the environment. In the area of SRW storage sites, radionuclide concentrations in the soil exceed the natural background value many times.

According to the data of the Committee on Ecology and Natural Resources (1995), ^{137}Cs concentration around the SRW open-air storage site made up 3.2-9.6 Ci/km^2. The gamma dose rate around the site was equal to 40-480 μR/h. ^{137}Cs concentration in the soil of the streambed area (the stream flowing from under installation №5) made up 0.9-76 Ci/km^2, the radiation background 34-30000 μR/h.

Within the CSE site there are rather powerful water streams resulting from atmospheric precipitation and flowing out of the above located territories (i.e., runoff or transit flows). As a consequence, radioactive substances issuing from the CSE site reach the water area of Bolshaya Lopatka Bay, which leads to the contamination of bottom sediments throughout the littoral zone adjacent to the CSE site. Despite this, the activity of marine water does not exceed background levels typical of the region and makes up 6-7•10^{-12} Ci/l.

Another pathway of the radioactive contamination within the territory under consideration is the spreading of radioactive substances from DSB of SF storage via the air.

Thus, the CSE in Andreeva Bay is a real (and not potential) source of Kola Peninsula environmental contamination.

The issues of storing RW and SF in Andreeva Bay are under constant check by the Murmansk Region Administration. To solve these problems, foreign investments are also attracted. For example, thanks to funds from the Norwegian Government, a project was realized in 1999 aimed at removing contaminated transit flows out of the damaged SF storage. As the result, the flow of contaminated waters (1•10^{-7} Ci/l) to Andreeva Bay has ceased. In 2000, a contract was signed with the Governor of Finnmark (province of Finland) to build supporting infrastructure in Andreeva Bay since there is a need in special protective installations to create safe work conditions for the personnel within the area of potential radioactive contamination. To carry out the contract, favorable conditions will be created in keeping with both Russian and international requirements. The following project of improving SF storage conditions at DSB is urgent: “Normalization of the Radiation Situation at Spent Fuel Dry Storage Block, Localization of Water Sources which Penetrate into the DSB, SF Inventory, and Developing Methods of SF Removal Using the Inventory Results”.

In keeping with the decree of the first meeting of the Co-ordination Council on Interactions in the Field of Nuclear and Radiation Safety in Murmansk region, a project "Nuclear and Radiation Safety of Murmansk Region for 2002 through 2006" is being developed by specialists at the present time. The project has the status of “regional program” and will include (among others) sub-projects related to the rehabilitation of installations in Andreeva Bay CSE.

CSE in Gremikha-settlement still represents a source of ecological risk for the near-coast and littoral zone of the Kola Peninsula and the Northwest region, as a whole.

The CSE installations and equipment were designed in 1950s. Principal CSE buildings were constructed in 1959 through 1965. The site area is 150,000 m^2. Underestimation of local natural conditions, the use of temporary RW and SF storage facilities, technological shortcomings when storing RW and SF, the lack of financing and aging of equipment during 35-plus years of operation has resulted in negative impacts on the environment and, in some cases, in dangerous radioecological implications at the CSE.

The results generalized in Table 2.24 make it possible to reveal environmentally hazardous constructions among the CSE installations.

Table 2.24 Characteristics of CSE Installations

№	Installation name	Installation №	Total area, m^2	RW volume, m^3, piece	Activity, Bq/l
1.	SFA repository	1	1128.0	106 SFA	$12.95x10^5$
2.	SEP repository	1B	694.0	6 SEP of NS with LMC	No data
3.	LRW repository	16AC	302.7	369.0	$6.5 \cdot 10^3$
		16AP		267.7	$1.07 \cdot 10^4$
		16BC	302.7	360.4	$3.4 \cdot 10^3$
		16BP		485.9	$1.43 \cdot 10^4$
		18A	63.6	50.5	$4.03 \cdot 10^3$
		18B	63.6	27.8	$8.14 \cdot 10^3$
		18V	33.2	24.9	$3.09 \cdot 10^4$
		20A	63.6	48.7	$1.02 \cdot 10^4$
		20B	63.6	14.4	No data
		20V	33.2	69.0	$1.48 \cdot 10^4$
		23	63.6	106.1	$8.25 \cdot 10^3$
4.	Floating tank-50	167	50	31.25	$2.52 \cdot 10^9$

№	Installation name	Installation №	Total area, m^2	RW volume, m^3, piece	Activity, Bq/l
5.	***SRW repository***	19	2100.0	150.0	No data
6.	SRW temporary storage site	—	300.0	550.0	No data

When analyzing Table 2.24 data, one can conclude that important amounts of both SF and RW of high activity are stored within the CSE installations.

It is worthy of notice that, if not in contact with the environment, neither SF nor RW are environmental hazards.

An analysis of the state of repositories and conditions of SF and RW storage at the CSE in Gremikha-settlement demonstrates the following:

- There are only local radioecological consequences of the CSE operation (only individual areas within the CSE site are contaminated);
- Outside the CSE site its radiation impact shows up in the form of increasing the radioactivity level of bottom sediments within the adjacent area; and

Principal negative consequences of the radioactive contamination of the CSE areas can be generalized as follows:

- There is a possibility of environmental contamination via the re-suspension of radioactive particles from the open-air site of SRW storage; and
- There is a risk of deep-ground contamination within the CSE site (in particular, due to LRW leakage).

As a whole, the radiation situation at the CSE in Gremikha-settlement is estimated as unfavorable; at the same time, in some buildings and installations as well as in some areas of the site, the radiation situation should be considered as hazardous.

Basic Lines of Radioecological Rehabilitation of the Installations under Consideration

Taking into account the state of buildings and installations storing SF and RW, one can determine basic lines of work aimed at their rehabilitation:

- SF and RW unloading;
- Decontamination and dismantling of out-of-date equipment and storage tanks;
- Integrated engineering and radiation survey of the equipment, buildings, installations and territories; and
- Making decision on the rehabilitation of buildings and installations:
  - renovation,
  - conservation,
  - liquidation.

The above lines can be realized through the following actions:

- Collection and adjustment of the data related to the state of installations;
- Carrying out research, design and development work;
- Fabrication and delivery of special transport and technological equipment, work tools and fittings;
- Unloading of SF and RW stored in the CSE repositories and their handling;
- Unloading of SRW stored in the CSE repositories and their handling;
- Processing of LRW stored in the CSE; and
- Rehabilitation of the CSE site, buildings and installations.

References to Part 2

2.1. Program of Current Monitoring over the Radiation Situation for 2000 in the Buffer Area and Radiation Control Area of FSUE “Sevmash PA” № 87.33-1.12.173-99;

2.2. Program of Current Monitoring over the Radiation Situation in the Environment of SMBE «Zvezdochka» of October 21, 1994;

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3. Analysis of the State and the Development of a Concept of the Ecological Monitoring in Northwest Region

3.1. Analysis of the Experience in the Creation and Use of Radioecological Monitoring Centers at Enterprises, Departments and in Regions of the Russian Federation

3.1.1. Departmental Centers

Centers of Minatom of Russia

Work aimed at generating automated systems (Automated System of the Control over the Radiation Situation - ASCRS) of Minatom of the Russian Federation was carried out mainly via the creation of subsystems, namely:

- ASCRS in Nuclear Power Plant (NPP) areas;
- ASCRS in the areas of nuclear and chemical complex enterprises; and
- ASCRS in the areas of enterprises with nuclear reactors and nuclear-physical facilities used for research purposes.

By the present time, a network of permanent dose rate monitoring stations has been created in locations of Minatom enterprises. A format of data exchange (via email) has been developed and used with success for over two years. Methods of presenting unclassified information via the Internet are elaborated in keeping with legislative requirements. Some systems (e.g., ASCRS of PA Mayak and ASCRS of St. Petersburg and Leningrad-region) were created in close interaction with local authorities and they represent virtually territorial systems operated under the control of Minatom specialists.

Situation-Crisis Center (SCC) of Minatom of Russia

By a special order of Minatom of Russia, the SCC of Minatom of Russia is entrusted to perform the duties of branch center, which collects and transmits information within the framework of both the branch ASCRS and USASCRS. Such information deals with the radiation and meteorological situation in locations of nuclear-dangerous and radiation-dangerous enterprises of the branch. To perform these duties, the SCC of Minatom of Russia has acquired all necessary hardware and specialized computer systems, which use geoinformation technologies including the radiation monitoring program complex of the SCC of Minatom of Russia (automated work place of manager and automated work place of expert). The program complex ensures [3.1]:

- Obtaining data on the radiation and meteorological situation from ASCRS sensors;

Processing, analysis and presentation (visualization) of values of the controlled physical parameters;

Automated signaling to the SCC of Minatom of Russia in the event of surpassing set points of both the warning and emergency alarm system;

Forecast of the radiation situation on-site with consideration for meteorological parameters; and

Automated transmission of files containing radiation monitoring data to other departments and organizations (in particular, to the Federal Information and Analytical Center (FIAC) of Roshydromet (RPA "Typhoon")) in keeping with the obligations of Minatom of Russia.

At the present time, data of the following nine ASCRS subsystems are collected by the central ASCRS (see Figure 3.1):

Kola NPP, Smolensk NPP, Rostov(Volgodonsk) NPP and Leningrad NPP (ASCRS NPP Subsystem);

SRC RF RIAR-NIIAR (ASCRS ПИР Subsystem); and

SUE AEChP(Angarsk CC), FSUE SChP(SCC) and FSUE MchP (GCC) (ASCRS NChC Subsystem).

Two further ASCRS subsystems are under connection:

SRC RF FEI; and

PA "MAYAK" (MAYAK PP).

Figure 3.1. Structures of Minatom Transferring ASCRS Data to SCC

State Unitary Enterprise Emergency-Technical Center (SUE ETC) Attached to RPA «V. G. Khlopin Radium Institute»

SUE ETC operates within the framework of activities aimed at creating automated systems of the control over the radiation situation in locations of radiation-dangerous enterprises of Minatom of RF. In particular, SUE ETC coordinated such work at nuclear-chemical complex enterprises, such as PA “Mayak”, Mining and Chemical Plant (MChP) and Siberian Chemical Plant (SChP). The creation of a standard data exchange format that made it possible to integrate measurement systems produced by different manufacturers into a unified information medium should be considered as a major achievement of the SUE ETC. At MChP and at ETC of SChP, local centers of information collection were created that integrated into global information network-systems. Data flows of public use and of restricted use were distinguished.

To generate the information system, four types of software were used [3.2]:

- Software serving specialized measurement equipment;
- Software providing data collection and processing, report generation, data receiving and sending, data filtration, and granting access to specialists as well as to general public;
- Well-proven network applications distributed at no charge in the course of many years and easily embedding into specialized information systems; and
- Standard business net software and DBMS to protect information, perform access authorization and system administration.

The system modularity as well as the application of standard public technologies makes it possible to install systems of different complication levels from an individual computer (having access to remote nets via a telephone line) up to a full-scale system, which serves information centers of regional or federal levels.

The system reliability is proven by four years of proper operation at the ETC and two years of operation at the involved enterprises of the branch. The integral data volume accumulated by the ASCRS after 1997 surpassed 150 MB. Since 1996, the data collected by ASCRS ETC and St. Petersburg has been presented on the Internet at the ETC server (http://www.atom.nw.ru).

Crisis Center of the Concern ROSENERGOATOM

ROSENERGOATOM State Concern is the major operation entity in Russia and, at the same time, it is one of the most important operation structures in the world. The Concern is responsible for the operation of eight NPP with various types of nuclear reactors (VVER, RBMK and FNR, i.e., neutron reactors, power water reactors, and boiling water reactors, respectively) with the integral electric power of about 21 Mw. A system of emergency response on NPP accidents was created and is functioning permanently within ROSENERGOATOM including the Regional Crisis Center (RCC) and a special group for emergency response and aid in a case of emergency. The group is supplied with all necessary information and tools to perform on-line NPP support in emergency situations.

At present the main tasks of the RCC are:

Keeping readiness of the response system and guidance of the response actions;

Notification in a case of emergency at NPP in the shortest possible time;

Heading all emergency response operations at a level of «ROSENERGOATOM»;

Creating real-time interaction between NPP in emergency and the involved research organizations and design offices;

In a case of emergency ensuring engineering support of NPP; and

Providing for stable and adequate public relations.

Every team of RCC dispatchers and engineers on duty ensures the readiness of all necessary information on emergency installation during 24 hours. Such information comes routinely via a special communication line from Local Crisis Center (LCC) of NPP.

Using up-to-date communications, videoconferences, for example, the RCC is connected with all structures involved in the emergency response. NPP themselves (connected via LCC with the central RCC) are included into the first group of such organizations. In addition to the nine NPP belonging to the Concern, Leningrad NPP (which formally is not integrated into the ROSENERGOATOM structure) is also connected to the RCC. Research institutes and design offices, such as: RRC «Kurchatov Institute», PhEI, EDO «Hydropress», Research and Design Institute of Power Engineering (RDIPE), RPA «Typhoon», IBRAE RAN et al., constitute the second group of the involved organizations. State structures connected with CC and taking part in emergency response actions form the third group.

Automated System of the Control over the Radiation Situation at Rostov NPP Area

In keeping with standard documents, such as: BSR-88/97, NRS-99, BSR-72/87, and in accordance with the Regulations of the RF Government № 600 of August 20, 1992 and № 1085 of November 02, 1995, Automated Systems of the Control over the Radiation Situation (ASCRS) are created at every operating NPP and NPP under construction that are considered as radiation-dangerous installations.

The main points of the ASCRS NPP concept can be stated, as follows:

ASCRS is to control in "on-line" mode the level of photon irradiation at the NPP site, in the buffer area and the radiation control area for every possible NPP operation modes including emergency situations up to beyond design-basis accidents;

ASCRS is to perform on-line computation and forecast of the NPP impact on the environment resulting from gaseous and aerosol releases;

ASCRS is to inform in real-time mode the NPP Radiation Safety Service, the NPP management, and crisis centers of Minatom regarding elevated levels of photon dose rate or of volumetric activity in NPP releases and effluents; and

ASCRS is to create a database on all controlled parameters.

The following modes of NPP operation and, correspondingly, the following ASCRS tasks should be distinguished:

Normal operation mode under which ASCRS is to present data on radiation levels at the NPP area (confirming the power plant safe operation) to NPP services, population and supervising structures;

A mode of elevated radionuclide releases from NPP, under which urgent real-time estimation and forecast of possible directions of radionuclide spreading are required; and;

A mode of emergency situations, including beyond the design-basis accidents, under which urgent on-line forecast and estimation of exposure doses on the population and the environment are necessary. These actions make it possible to create recommendations for management bodies in order to realize appropriate countermeasures aimed at decreasing to a minimum dose loads on the population.

The information formed by the ASCRS is destined to NPP services and management, to the population residing within NPP radiation control areas, as well as to the RCC of "ROSENERGOATOM" Concern and to the Situation-Crisis Center of Minatom of Russia.

In keeping with the recommendations of the Russian Research Institute for Nuclear Power Plants Operation specialists, 19 settlements were chosen within the 30-km radiation control area of Rostov NPP where stations were equipped with photon dose rate sensors.
All real-time information (of the control stations within the radiation control area, the NPP site, weather station and control channels in ventilation ducts) reaches the Central Control Station (CCS ASCRS) at which the controlled parameters are measured and recorded. CCS ASCRS is placed into a well-protected room that makes it possible to carry out "on-line" control at any situation at NPP. The system performs complete internal auto-diagnosis; it also archives all accepted data, actions of operators and the state of the system.

Via a local network the CCS is connected to Automated Work Places (AWP-1 and AWP-2) [3.3]. AWP-1 is aimed at putting information at the disposal of the duty operator of the radiation safety department, whereas AWP-2 is aimed at calculating release parameters and forecasting the impact of NPP on both the environment and the population.

To perform periodic examination of measuring channels without dismantling, ASCRS includes a set of portable check-up equipment comprising containers with ionized radiation sources (IRS) and special holders to arrange the IRS on detecting structures.

At the second stage of Rostov NPP ASCRS creation, the following systems are to be created:

- posts for control over the air and water media;
- mobile radiometric control systems;
- complex post for control over the ventilation duct releases; and
- a reserve control post outside the NPP to collect and process information in a case of CCS ASCRS failure.

Automated System of the Control over the Radiation and Chemical Situation at Angarsk Electrolysis and Chemical Plant (ASCRS AEChP)

The ASCRS AEChP is mainly aimed at obtaining the necessary information on the radiation, chemical and meteorological situation and their variations:

- under normal operation of the plant to confirm its safe state;

when detecting deviations from the safe operating conditions, to transmit this information to duty personnel, the plant management and supervising bodies; and

when revealing an excess over safety limits in a case of accident, to prepare the needed information aimed at estimating the accident extent, to put into operation a plan of emergency response actions, to take measures for personnel and population protection as well as to perform actions aimed at eliminating the accident and its possible implications.

Emergency situations at AEChP can result from radionuclide releases into the environment and air pollution by hazardous chemical substances. The automated control system was created with consideration for both the radiation situation and chemical situation.

From the structural standpoint, the ASCRS AEChP is a network distributed over the buffer area and a housing area of the town, which consists of seven stations controlling dose rate values, one weather control station, two Information-Management Centers (IMC) and of the appropriate software [3.4].

The control station equipment makes it possible to measure data automatically every eight minutes, and to collect and store information embracing a long time period. Different-type inquiries allow the user to obtain data for a period of time he is interested in. In a case of any parameter deviation beyond the set points, the parameter in question will be measured automatically every two minutes, while the results will be transmitted to Information-

Management Center of ASCRS AEChP and the Situation-Crisis Center (SCC) of Minatom of Russia.

To perform information exchange with local authorities, a special analytical center is equipped at the ecological department of the town administration. The data on the radiation and chemical situation of the control station located within the housing area of the town are communicated via automatic telephone lines. Since June 2000, every eight hour data communication via email from ASCRS AEChP to SCC of Minatom of Russia has been carried out. These data characterize local radiation, chemical and meteorological situation.

The ASCRS system was generated using the KAMAT geographical information system, which makes it possible to scale the topographical basis of the plant area with the available control stations.

Within the framework of the first ASCRS phase, a program was introduced at the plant referred to as «Forecast of the Consequences of Accidental Release of Virulent Poisonous Substances in a Case of Accident (Destruction) at Chemically Dangerous Installations and on Transport Facilities».

System of Radiation and Ecological Monitoring of the State Research Center of the Russian Federation «Research Institute of Atomic Reactors» (SRC RF RIAR)

At SRC RF RIAR a system of control over the radiation and ecological situation within the site and the near-zone was developed. The system includes an in-site ASCRS and «Zone» Ecological Program Complex (EPC) [3.5]. Control over the radiation fields within the site is carried out via direct measurements by a number of dosimetric sensors, unified into a system of on-site ASCRS. Control over fields of radioactive substance concentration in the surface layer of air and exposure doses is performed through calculations.

The information obtained by the ASCRS subsystems is processed at the information and analytical center of ASCRS and is visualized to the operator in the form of plots, tables and messages. A part of the data is formed automatically in message-form and is transmitted to the upper level of the branch ASCRS. Personal computers (PS) of the information and analytical center constitute a laboratory network possessing an output to servers of the information-switch node of the RIAR local network. Via the local network, the data of ASCRS are transmitted to RIAR users and via the Internet to the upper level of the branch ASCRS, to the emergency crisis center and regional management bodies.

Within the framework of the ASCRS section of the SRC RF RIAR created to date (first phase), dosimetric control at special points (control posts) on-site is ensured. Ten control posts are arranged along the perimeter of the fenced-off area in different directions from the ventilation duct. Control posts are also placed at locations of installations dealing with processing, storage and disposal of RW, at the 40m level-mark of the administrative building to control gas releases out of the duct of the ventilation center, and in a sewer hole.

To transmit control post data to the on-site ASCRS, a cable network is used. Cable communications are laid at the site area using the existing sewer system. Telecommunications are realized via the enterprise automatic telephone system. Control posts of all subsystems communicate the data to PC directly or via concentrators using serial links. PC ensure:

- receipt and processing of the information issuing from the automated weather station of the enterprise, from the control post of ventilation center and the mobile radiometric laboratory. This information is used to create a rough forecast of the environment contamination extent and calculate potential population exposure doses on the basis of Gauss transfer and dispersion model. The operator can introduce supplementary data of laboratory sample analyses; and
- automatic collection, processing and presentation of the site dosimetric control data (in the future, of the buffer area and the radiation control area).

One PC is the server of ASCRS laboratory network and allows for:

- on user request, forming, routing and transmitting messages via email or in “remote access”-mode;
- automatic generation of routine messages and their transmittal to the upper ASCRS level in keeping with the accepted formats, logs and schedule;
- creating and maintaining databases and archives on the radiation situation, doses, calculated models, potential to eliminate emergency situations, accident scenarios, reference regional demographic data, etc;
- obtaining hard copies of analysis results, recording requests and answers; and
- authorizing data access with consideration for the user status.

ASCRS makes it possible to perform real-time control over the radiation situation, to effect light signals and sound signals when control levels in force are exceeded, and to visualize plots, tables and different messages on display screens. The basic ASCRS function is the well-timed detection of appreciable deviations in the radiation parameters within the controlled territory and the identification of the hazard source, i.e., of the installation in emergency.

Centers of Roshydromet

Federal Information and Analytical Center (FIAC)

The creation of a system of collecting, processing and generalizing information on the radiation situation in Russia began in 1961. Based at hydro-meteorological stations, a network of observation stations over radioactive aerosol concentrations in the air, radioactive depositions, soils and surface water contamination was created. Systematic observations over the contamination of the air, bottom sediments and ocean water using oceanographic research vessels and "weather vessels" was organized. In 1964, aerial radiometric mapping and radiation surveying was started.

Since 1964, RPA "Typhoon" has been entrusted with a task of scientific and methodic guidance over the radiometric network (here these issues have been studied since 1958). To collect and analyze information on the radiation situation, a Federal Information and Analytical Center (FIAC) was created within the framework of RPA "Typhoon" [3.6].

In a special Government regulation of 1989 the creation of a State Automated System of the Control over the Radiation Situation (SASCRS) was suggested and in the subsequent Regulation of 1992 the creation of a Unified SASCRS (USASCRS) was planned.

In recent years, work on USASCRS creation has been performed by FIAC using the functioning network of the Radiation Monitoring Service (RMS) stations in close collaboration with the Environment Radiation Monitoring Laboratory. Stations transfer in "on-line"-mode the information on gamma-irradiation in the environment to FIAC via "Weather" Automated Data Transmission System (ADTC). Monthly joint reference data on the current radiation situation in Russia (including territories with radiation-dangerous installations) are communicated to Roshydromet. At the present time, most of the data on the radiation situation cannot be obtained automatically at the control points.

Cheliabinsk Center of Hydro-Meteorological Service (CHMS)

The radiation monitoring system of Cheliabinsk Regional Center on HydroMeteorology and Monitoring of the Environment represents an element of the Roshydromet vertical structure. Within this framework, Cheliabinsk CHMS realizes the following functions [3.7]:

collection and accumulation of data on the radiation situation within the Cheliabinsk region;

creation of databanks on information flows from the observation network and on laboratory measurements; and

communication of the integrated information into databanks of higher vertical levels.

The radiation environmental monitoring performed by Cheliabinsk CHMS is an element of the territorial system of radiation monitoring. The supplementary tasks of the Center are:

reliable and efficient detection and estimation of abnormalities in the radiation situation within the area of a nuclear installation location; and

provision of complete information on the radiation situation variations for authorities, civil defense services and emergency services.

To carry out the above tasks, the following systems are created and are operating at Cheliabinsk CHMS:

a network of «manual» dosimetric control stations (50 units) at which the gamma-background is measured using DBG06T dosimeters three to eight times a day;

a network of radioactive soil deposition sampling (36 control stations);

a network of radioactive aerosol sampling (seven control stations);

a network of deposition sampling to detect tritium (six control stations); and

a network of 17 automated gamma dose-rate control stations around radiation-dangerous installations of the Cheliabinsk region (PA «Mayak», RFNC ARRITPh).

Hydrometeorological stations of the Cheliabinsk region are computerized. Via modem lines, the data on current variations of the radiation background come to the central CHMS server under a scheduled mode. From there, the data are transmitted via local network to an automated work place at the radiometric laboratory. It is here that the information is analyzed, processed and recorded into a database using computer programs. If necessary, the data can be visualized in the form of tables or schematics. The samples of atmospheric air coming from control stations are analyzed in the radiometric laboratory (integral β- and integral α- activity, γ-spectrometric analysis, ^{90}Sr) and the obtained results are also generated into an electronic database.

The network of automated dosimetric monitoring functions as follows: information from automatic sensors of gamma dose rate measurements is transmitted every 20 minutes via a radio-channel or telephone communications to an intermediate server arranged at one of the weather stations. Next, under a scheduled every three hour operation mode (in a normal radiation situation) or as new information becomes available (in a case of emergency), the data enter the center server of the Cheliabinsk CHMS. From here, via local network, these data are transmitted to work computers at the radiometric laboratory.

Everyday information on gamma dose rate variations measured by «manual» dosimetric stations is also transferred to FIAC of Roshydromet (Obninsk-town) via communication lines.
A network of consumers (users of Hydromet radiation monitoring data) is created in the Cheliabinsk region. It includes the town authorities, and the Central Directorate on Civil Defense and Emergency Situation Affairs. Users possess automated work places ensuring reception of the transferred data via modem communication lines in the form of tables or maps.

In the central server of Cheliabinsk CHMS, specialists of FIAC Roshydromet installed a program for receiving and mapping forecast information related to the spreading of accidental radioactive contamination. When an emergency arises with radionuclide release into the environment beyond the buffer area of a nuclear installation, an official Roshydromet forecast on the radiation incident development is received at Cheliabinsk CHMS within two hours and then is communicated to the authorities. Such efficiency makes it possible to realize measures for population protection against the radiation impact in a rather short space of time.

Base Territorial Subsystem of the Radiation Situation Survey (BTSRSS) within the Framework of RF Hydromet

Base Territorial Subsystem USASCRS of Roshydromet (BTSRSS) is designed to survey the radiation situation in Russia: in regions where radiation-dangerous installations are located, within contaminated territories due to radiation accidents, and in areas of RW storage and disposal (including the marine medium). The subsystem tasks also include control over the transboundary transfer of radioactive materials and the radiation survey. The information support of all-level authorities and managerial structures to ensure the radiation safety in the Russian Federation is also carried out.

BTSRSS is aimed at improving the observation network of the HydroMeteoological Service to perform control over the environmental media contamination in the Russian Federation.

BTSRSS is entrusted with adjusting both the measuring and methodic basis of the HydroMeteorological Service in accordance with the requirements of the legislation now in force relating to ensuring radiation safety and automating the processes of the network operation. BTSRSS uses functional-territorial principles and consists of three structural units – the information receiving, analysis and generalization, i.e., "Measuring Unit", "Information-Analytical Unit" and "Driving Unit". According to the design, BTSRSS will include five functional subsystems differing in area and mode of the environmental contamination monitoring. At present, a performance specification is developed and approved to create one such subsystem (ASCRS of Radiation-Dangerous Installations (RDI)). Investigations and specifications are being carried out to generate the system elements in close interaction with the systems of specialized control of Minatom of Russia.

Centers of Ministry of Environment and Natural Resources (MENR) of the Russian Federation

In 1999 a pilot program of the first phase of USASCRS was created and put into operating testing. The program is aimed at the practical working through of information interactions of departmental-territorial subsystems and ensuring data exchange on the radiation situation monitoring and the state of radiation-dangerous installations. As a result of two years operation, a unified information network was created using TCP/IP data communication protocols of leading information-analytical centers of departmental subsystems of Minatom, MENR, Emercom, Ministry of Defense, Ministry of Agriculture, Gosatomnadzor, Roshydromet and territorial ASCRS of the Tomsk region.

When creating the pilot program of the USASCRS first phase, the following tasks were carried out [3.8]:

- integrating on-line data exchange on the radiation situation coming from departmental and territorial control systems into the distributed information structure of the pilot USASCRS program;
- perfecting principles of early user notification, via USASCRS information resources, regarding exceeding parameter limits at installations and controlled territories based on processing on-line data of the radiation situation with an estimate of their reliability and trustworthiness;

- debugging information exchange schedules within the framework of the pilot program;
- equipping operating federal and territorial Information and Analytical Centers (IAC), which form part of the pilot USASCRS program, with necessary supplementary telecommunication equipment and computer techniques; and
- experimental working through of basic principles of generating the information structure for the Automated Information Control Subsystem (AICS) of USASCRS.

In the course of experimental operation of the first phase of the ASCRS program in 2000, important practical experience has been accumulated, and a large amount of data on the radiation situation (about 455 MB) has been collected. Note that these data are accessible for all the pilot program participants.

On the federal level, an Information and Analytical Center of the Subsystem of the Control and Survey over the Contamination Sources, as a part of the USASCRS, was created at the State Institute of Applied Ecology (SIAE).

The subsystem of the control and survey over the contamination sources, which forms a part of USASCRS (ASCRS «Source») is entrusted with the following tasks:

- carrying out of automated control over the environmental radioactive contamination resulting from anthropogenic sources,
- providing officials of RF environmental structures with objective and complete information required to address issues related to environmental protection, and
- ensuring information support for different-level public authorities and managerial structures on radiation and ecological safety in the Russian Federation.

In a case of an initiating nuclear accident, ASCRS-«Source» performs the information support of work aimed at eliminating the consequences of the emergency situation.
New hardware and software providing for information interactions with territorial components of the subsystem and the central IAC of USASCRS departmental subsystems and services are been developed and put into experimental operation. In 2000, an operating prototype of the base GIS ASCRS «Source» was generated.

To create an experimental component of the territorial level ASCRS, the area of Kalinin NPP (Tverskaya region) was chosen. In 2001, work began on equipping a territorial IAC and some stationary measuring stations and a mobile control complex will be put into experimental operation. These actions will be aimed at experimental working through of the procedures of obtaining measurement data, their communication, processing, analysis, presentation and archiving, and ensuring information exchange with other IAC of both territorial and federal levels.

3.1.2. Territorial Centers

The issues of radiation safety in Russia (as a part of ecological safety) are under the joint competence of the Russian Federation, on the one hand, and the RF subjects, on the other hand. By this is meant that the public authorities of Russia are responsible for radiation safety at the regional level and exert influence on the situation through the elaboration and making of appropriate decisions.

Territorial Network of Automated Control over the Radiation Situation in St. Petersburg and Leningrad Region

An automated system of control over the radiation situation in the St. Petersburg and Leningrad region was created and is supported via funds of the federal budget and the budgets of St-Petersburg and Leningrad region. The system is generated on the instrumentation base developed by RPA «Radium Institute» (RTC «RION») [3.2].

The information system is developed and supported by specialists of Central Directorate of Emergency-Technical Center. It includes software to query control stations, a DBMS to collect and store information, report generating facilities, data communication devices and access facilities. Using this system, network schemes are worked through, which allow for stable operation of the information-measuring system and automatic data exchange realized at the ASCRS SChP and ASCRS MChP systems in operation.

Within the territorial radiation control network, up to 33 dose rate measuring stations and two weather stations were in operation; unfortunately, financial problems resulted in degradation of part of the system that belonged to the Leningrad regional government.

Principal information consumers are: Duty Service of the St. Petersburg Governor, Environmental Department of St. Petersburg, Northwest Regional Center of EMERCOM, State

Sanitary and Epidemiological Inspection, and the Central Directorates on Civil Defense and Emergency Situations in St. Petersburg and Leningrad region.

Territorial Center of Murmansk-Town

An automated system for control over the radiation situation is especially pressing for Murmansk region, in which a unique concentration of units and installations using nuclear technologies has occurred. However, the lack of their own (off-departmental) information provides no way of carrying out quick response and efficient decision making for population protection in a case of radiation incident or accident.

At present, the territorial ASCRS of Murmansk region (MR ASCRS) includes the local Kola NPP ASCRS and a territorial center created in 2000 based at Murmansk Department of HydroMeteorology and Environmental Monitoring [3.9]. For the time being, the center of MR ASCRS carries out the functions of collecting information and detecting the radiation background variations at a level of incident/accident at radiation-dangerous installations.

Territorial Radiation Monitoring System of Cheliabinsk Region

Work on creating automatic control networks has been performed in Cheliabinsk region since 1992 within the framework of departmental structures. A developed system of control stations is operating within the buffer area and the radiation control area of PA «Mayak»; five automated stations of gamma dose rate control were established in the region settlements by order of the Regional Committee on Ecology and Natural Resources.

In 1996, in keeping with the Regulation № 1085 of November 2, 1995 of RF Government, a program of creating a territorial USASCRS subsystem in Cheliabinsk region was accepted and coordinated with Roshydromet and MNR of the Russian Federation.

The territorial subsystem of the radiation monitoring is based on the following functional principle – the development of departmental services and the creation (within these departments) of a decision-making information support system for regional authorities and managerial bodies. Functional subsystems consist of an automated and non-automated observation network, and information-analytical structures that process primary information.

Automated System of the Control over the Radiation Situation in Tomsk Region

The following principal factors determine the radiation situation in the Tomsk region:

enterprises considered as “especially dangerous nuclear and radiation installations” by the Regulation № 238 of March 3, 1995 of RF Government, such as: Siberian Chemical Plant (SChP) and the research reactor of Tomsk Polytechnic University;

radioactive traces of both the Chernobyl accident and Totsk exercise;

traces of Semipalatinsk and New-Land testing grounds; and

operation of 38 different institutions and enterprises dealing with radiation substances and other IRS.

The State Committee on Ecology of the Tomsk region and the Tomsk Center of Hydrometeorology and Environmental Monitoring (TCHEM) with the support of authorities of the Tomsk region and Seversk-town, initiated the creation of the Tomsk region ASCRS [3.10]. The first phase of creating the automated system of the control over the radiation situation in Tomsk region (ASCRS TR) was performed in 1993 through 1995 following an accident at the radiochemical shop of SChP. During the period from 1995 to 1999, 26 stand-alone stationary dose-rate-measuring stations were put into operation, and three centers of primary information collection were equipped.

A unique peculiarity of the ASCRS TR is that at the initial stage of its creation many organizational and technical problems were solved with success. This made it possible to realize and improve an integrated system, which also included the Seversk-town Close Administrative and Territorial Structure (CATS).

The system is built up in the form of two circles of control stations. The first circle is located within the Seversk CATS fenced-off area in the immediate vicinity of SChP, while the second (external) circle is situated in settlements in the 30-km area outside the CATS boundaries. Hardware and software of ASCRS TR were developed by RTC «RION» of RPA «V. G. Khlopin Radium Institute» (St. Petersburg). At present, work is being carried out to replace out-of-date equipment at control stations, to equip some of the stations with automated devices for measuring weather parameters (wind direction and speed, temperature, atmospheric pressure and humidity) and with information tableaus of «creeping line»-type.

The automated system of the control over the radiation situation in the Tomsk region is built using a hierarchical approach and consists of the following subsystems:

- information subsystem for monitoring and measuring the radiation situation parameters;
- analytical subsystem for collecting, processing and analyzing primary results, information conversion and coding in order to transfer to upper hierarchical levels;
- generalized subsystem for estimating status, preparing proposals on alternative responses in a case of situation variation, and calculating the needed resources to store information; and
- subsystem for internal and external communications, transmission of both data and instructions.

By now, the first item within the existing ASCRS TR is partly completed (stations of gamma dose rate measurement); while the second item (center of primary information collection) is under construction.

An analysis of the social, economic and environmental peculiarities of the Tomsk region, of the distribution of radiation-dangerous installations, the population density, surface waters and agricultural lands within the region, as well as an analysis of potential sources of transboundary radionuclide transfer makes possible the following suggestion: Stand-alone stations of gamma dose rate measurements should be placed within the region using a radial-zonal principle.
The external ASCRS circuit of about 100 to 120 km in length passes over a line for locating primary information collection centers (settlements). The internal circuit of the ASCRS subsystem (nine stations of Seversk CATS) is created to improve the control over the SChP workshops.

The Tomsk Center on HydroMeteorology and the Environmental Monitoring operates the ASCRS; the Regional Center of the Radiation Safety and Control is designated as a coordination body by special decree of the Tomsk regional Governor.

Nine laboratories are chosen as basic ones to analyze the radioactive contamination of the soil, waters, air, foodstuff, construction materials, etc. They include:

- laboratory of Tomsk Center of HydroMeteorological Service of on-line radioactive release inspection;

laboratory of State Agrochemical Service Station referred to as «Tomskaya laboratory»;

Seversk CATS laboratory of the Committee on Natural Resources;

Tomsk Center «Tomskgeomonitoring»; and

Laboratory the Committee on Natural Resources of Tomsk Region.

The main body of the ASCRS TR is the center for generalizing information (i.e., the territorial information and analytical center) designed to estimate the radiation situation in Tomsk region, as a whole, and in any of its districts, in particular. The center is entrusted with the following tasks:

confirming the reliability of the results of estimations;

preparing proposals on alternative responses in a case of the situation variation;

calculating the needed resources; and

storing information and performing other functions (e.g., dispatcher distribution of operation algorithms to centers collecting primary information).

Territorial Subsystem USASCRS of Perm' Region

The USASCRS of Perm' Region has been developed since 1998. The necessity of creating an automated system of control over the radiation situation in the Perm' region results from the following factors. No radiation-dangerous installation of federal ownership exists in the region. However, there are sources of radiation hazard due to both industrial development in the territory and the USSR «radiation heritage».

Elevated concentrations of uranium, thorium and their daughters (including radium) are typical for the rocks forming the geological structure of the region. Oil production (one of the most important branches of regional industry) results in an appreciable environmental contamination by natural radionuclides. In the course of 1969 through 1987, eight Underground Nuclear Explosions (UNE) were setoff within the Perm' region at a depth of 127 m to 2020 m.
In keeping with the law «On the Radiation Safety of the Population», the Perm' region authorities made a decision to create an automated system of control over the radiation situation for the region within the framework of the USASCRS. The ASCRS of Perm' region is considered by the regional authorities as an information-measuring system aimed at making

administrative decisions in the area of environmental protection and ensuring population safety. As the result, it was decided that the Perm’ ASCRS would represent a component of the unified territorial system of ecological monitoring.

The Territorial Analytical Center Perm’ ASCRS represents an information-computer center providing for automated collection of radiation control data and their registration into a specialized data warehouse [3.11].

During 1999 through 2000, two ASCRS programs were put in operation at Ossinskoie oilfield and Guezhskoie oilfield. This work made it possible to automate the process of measuring ^{137}Cs activity of the water-oil mixture and to ensure permanent control over pumping processes. Permanent automated radiation monitoring at oil fields is realized using «Spider»-system elements. An automated device performs continuous measurements of the activity and preliminary processing of the gamma-irradiation spectrum of the mixture flowing in the pipe, then transfers the results to a processing center via telephone lines.

Automated System of the Control over the Radiation Situation in Irkutsk Region as a USASCRS Component (Baikal ASCRS)

170 enterprises of the Irkutsk region are dealing with radioactive substances and IRS. There are also two enterprises whose production activities relate to both the treatment and storage of radiation-dangerous substances: SUE Angarsk Electrolysis Chemical Plant (AEChP) and FSUE Irkutsk Special Radiation Safety Plant «Radon». Also, two underground nuclear explosions were setoff within the region under consideration.

The Baikal ASCRS is aimed at automating the following [3.12]:

- systems of control over radionuclide releases into the environment from technogenic sources located in the region, which can potentially result in environmental contamination;
- systems of control over environmental media contamination;
- systems controlling the contamination of inhabitable zones and population exposure doses, including doses to personnel dealing with IRS; and
- systems transferring information on the radiation situation and performing its analysis, processing, storage and presentation.

At present, the following systems of control over the radiation situation are developed and put into operation in Irkutsk region:

- local automated system of control over the radiation situation of FSUE Irkutsk Special Radiation Safety Plant «Radon» (ASCRS Radon);
- measuring-information system of the local ASCRS of Angarsk EChP (MIS ASCRS);
- automated system of radiation-hygienic inventory of installations and enterprises, which use IRS in Irkutsk region (installed at the State Center of Sanitary and Epidemiological Inspection);
- automated system of control over the radiation situation at hospitals, clinics, etc. of Irkutsk region (installed at the Public Health Committee attached to the Irkutsk regional administration); and
- information-analytical system of the registration and control over RS and RW in the Irkutsk region (the system is operating on the basis of FSUE «Radon» in keeping with the Decree № 399-p of June 15, 1998 of the Irkutsk regional Governor).

A system of radioactive contamination monitoring by the Irkutsk Department of HydroMeteorological Service (DHMS) is operating in the region. The system is aimed at early notification in a case of emergency and forecast of radioactive contamination spreading in the environment using the data of DHMS weather stations. At present, the system of radioactive contamination monitoring of the Irkutsk DHMS is not automated.

A Geoinformation System of Public Authorities (GIS PA) attached to the Irkutsk regional administration has been generated. Within the framework of the GIS PA, special district-level “certificates” have been developed, which comprise economic, demographic, social and other characteristics.

3.1.3. Conclusions of the Chapters 3.1.1 and 3.1.2

In recent years, important progress was made toward the creation of specialized, departmental and administrative territorial centers of radioecological monitoring. However, in most cases such centers are solving their own local tasks, and their integration into a unified information system is hampered by departmental limitations, on the one hand, and by different formats of data storage and presentation, on the other hand.

Centers of Minatom of Russia are developed and equipped in the best way.

Most of territorial centers of the radioiecological monitoring attached to administrative bodies of regions were based on the Roshydromet departmental territorial systems. However, in keeping with its status, Roshydromet does not control the situation in radiation control areas of enterprises; here the radiation monitoring is imposed on enterprises themselves. No specialized ASCRS is available at installations involved in nuclear vessel handling after the decommissioning.

Technical issues related to the creation of distributed information networks of both ecological and emergency monitoring, which unify different-degree slave segments, can be resolved with success on the basis of already existing structures.

Information centers of ecological monitoring cannot substitute for regional and departmental committees on emergency situations, since it is precisely these committees that make decisions in a case of emergency. However, information-analytical centers are rather effective when collecting, analyzing, processing and storing information needed to make managerial decisions related to both normal and off-normal operation of radiation-dangerous installations.

When creating systems of ecological monitoring and their subsequent integration into USASCRS and Unified State System of Environmental Monitoring (USSEM), the system operation schedule should be determined and the following issues should be concretized at designing level:

Types of data to be communicated and data exchange format;

Requirements for software and hardware to support different-level subsystems;

Requirements for communication channels to perform data exchange;

Methods and techniques of exchange with contact information related to administrative and technical issues;

Methods and techniques of the information protection and validation of the information sources; and

Ensuring access of regional authorities to the information of subsystems located within their area of responsibility.

3.2. Analysis of the State of the Radioecological Monitoring in Murmansk Region and Arkhangelsk Region of Russia

3.2.1. Control over the Radiation Situation at Russian Shipbuilding Enterprises

The radiation situation at enterprises is controlled in working areas (shops, slipways, laboratories) and on nuclear vessels under construction, repair and utilization. The state of the environment is also under control because of its potential radioactive contamination. In addition, radiation-hygienic examination of the personnel is performed for both normal and off-normal operating conditions of the concerned enterprises.

The main enterprises of the branch, which perform the radiation monitoring, are listed below:

FSUE SMBE «Zvezdochka» of Severodvinsk-town, Arkhangelsk region;

SUE «Sevmash PA», Severodvinsk, Arkhangelsk region;

«Nerpa» Shipyard, Snezhnogorsk-town, Murmansk region;

“Zvezda” Fareast Plant, Bolshoy Kamen’-town, Primorskij kraj;

PC «Amur Shipyard» in Komsomolsk-on-Amur, Primorskij kraj; and

SC «Baltiyski Plant» in St. Petersburg (if nuclear vessel construction is recommenced).

Radioecological survey within both the buffer area (BA) and the radiation control area (RCA) of the enterprises 1 through 3 is performed by regional sanitary and epidemiological inspections and CRI CM «Prometheus» Departmental Service.

Extent and Peculiarities of the Radiation Monitoring at Rossudostroenie Enterprises

In keeping with the departmental standard document (RD AEISh 2946-99), programs of the current control are in force at the enterprises under consideration to carry out permanent monitoring over the radiation situation. It includes the control over:

γ-radiation dose rates, β-particle and neutron flux density at work places, adjacent rooms and within the enterprise site;

surface contamination of the site, working areas and other most visited areas including RCA;

levels and radionuclide composition of the environmental component contamination;

radioactive contamination of the enterprise water areas;

activities of RS releases in the air;

RS concentrations and their radionuclide composition in effluents disposed directly into water sources and the sewer system;

All stages of RW handling (collection, disposal, neutralization and storage);

Levels of the environmental component contamination beyond the enterprise site;

Contamination of transport facilities; and

Exposure levels of the group "B" personnel and of the population living in the RCA.

The contamination monitoring is carried out via direct measurements on-site using stationary or portable devices as well as via taking samples and their subsequent radiometric, spectrometric and radiochemical analyses.

Personal dosimetry of the personnel consists of:

the control over external doses of β-radiation, X-radiation, γ-radiation, neutrons and mixed radiation using personnel dosimeters; and

the control over RS intake and concentrations in the whole body or in individual "critical" organs.

When performing most hazardous radiation operations, a special program, which takes into account special features of the actions to be performed and their location, supplements the current control program. The special program ensures more complete recording of RS releases into the environment, an estimate of their spreading and the possibility of estimating doses to the group "B" personnel and the population.

On the base of the order № 108 of the Rossudostroenie General Director of December 26, 2000, FSUE CRI CM «Prometheus» is appointed a Departmental Information and Analytical Center (DIAC) to perform the registration and control of RS, RW and IRS at Rossudostroenie enterprises and institutions [3.13].

DIAC is entrusted with collecting, processing, generalizing and analyzing information at departmental level related to the availability, use, transportation, treatment, utilization, storage and disposal of RS and RW. The prime goal of DIAC is to provide the Rossudostroenie leaders with analytical information and present (in accordance with the established procedure) the information on RS and RW availability and transportation within Rossudostroenie enterprises to:

state authorities;

government bodies dealing with the use of atomic energy;

regulatory agencies dealing with nuclear, radiation, technical and fire safety when using atomic energy; and

central Information-Analytical Center (CIAC) of Minatom of Russia.

Radiation Monitoring System

The system of radiation monitoring developed for Rossudostroenie enterprises (SRE «Altair») consists of two segments:

Automated Control System (ASCRS) at the enterprise site; and

Radioecological monitoring (surveying) within the buffer area (i.e., the 3-km area around enterprises).

The system under creation is aimed at solving different tasks for the sake of the branch enterprises (and for the branch, as a whole) as well as for the sake of local and federal authorities. This goal can be attained through the ASCRS unification and compatibility with regional systems of control over the radiation situation as well as with the USASCRS.

3.2.2. Murmansk Territorial Automated System of the Control over the Radiation Situation (MT ASCRS)

The radiation situation in Murmansk region is determined by the activities of the nuclear complex. Over 200 nuclear reactors are operating in the region at nuclear icebreakers, nuclear submarines (NS) and the Kola NPP. Over 100 reactors of decommissioned nuclear submarines are to be utilized. Along with nuclear icebreakers, NS and NPP, installations of supporting infrastructure are also sources of potential radiation hazards. The radioecological danger results from the technical state of repositories storing spent fuel (SF), and solid and liquid radioactive wastes (SRW and LRW).

On 27 January 1993, the Public Deputy Council of Murmansk region approved a «Program of Improving Nuclear and Radiation Safety in Murmansk Region for 1993 through 2000». On the issue of «Improving the Radiation Monitoring», the Committee on Ecology and Natural Resources of Murmansk Region together with Murmansk Department on Hydrometeorology and the Environment Monitoring were entrusted with creating a regional unified automated system of control over the radiation situation by 1995.

Murmansk Department of HydroMeteorological Service (MDHMS), as a state structure authorized to perform environmental radiation monitoring, was appointed a center of collection, storage and primary analysis of on-line information of the territorial ASCRS [3.14]. MDHMS possesses a multi-branch network of weather and radiometric survey stations of permanent (24-hours a day) operation unified by reliable channels of information collection and communication. If necessary, the MDHMS specialists are able to predict the trajectory of a moving radioactive cloud.

In the early 1990s, MDHMS performed daily measurements of exposure dose rate at 33 stations; the integral β-activity of depositions was measured at eight stations and the volumetric aerosol activity at three stations (Figure 3.2.1). However, the radiation monitoring database available at that time did not allow for efficient revealing of radiation incidents.

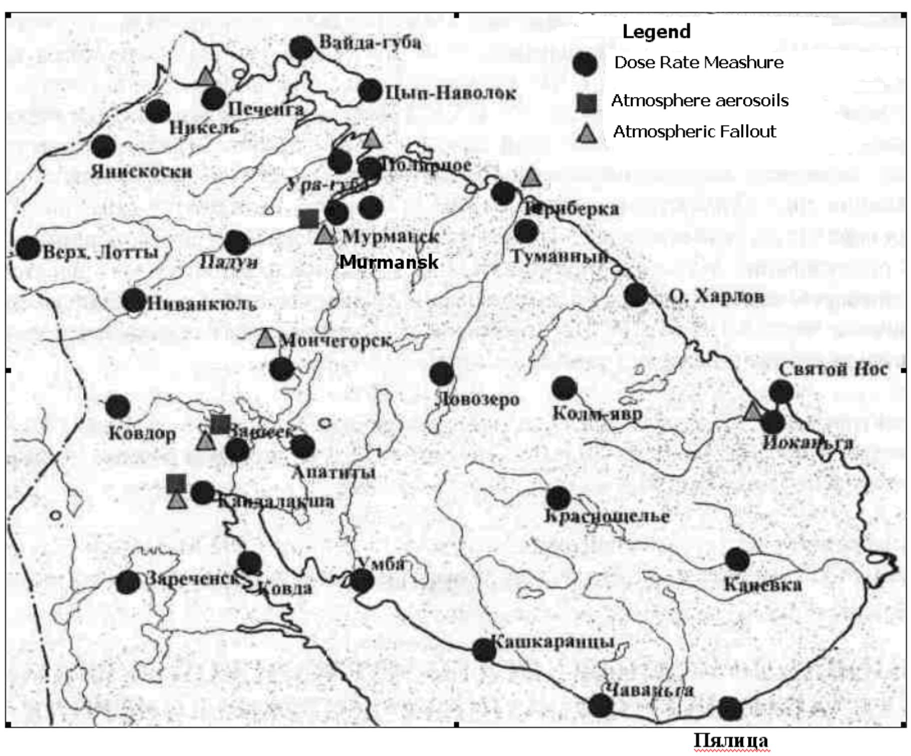

Figure 3.2. Map of the Radiation Monitoring Network of Murmansk DHMS

In keeping with an agreement between the governors of Lapland and the Murmansk region, in 1994 Finland transferred and put into operation a system of radiation monitoring (AAM-95), which consists of eight real-time automated sensors of gamma dose rate measurements. Since then, the results of AAM-95-system measurements have been communicated to the database of Murmansk DHMS in an around-the-clock on-line mode.

Simultaneously, the authorities of Finmark delivered a gamma-spectrometer, which was installed at Verkhnetulomskiy-village weather station. The data from Norwegian gamma-spectrometers have been also communicated to the ASCRS of Murmansk region (note that the radioecologists of the Kola Peninsula have free access to the current information on the radiation situation in Norway).

To create the Murmansk territorial automated system, a general performance specification was approved on the 29th of December 1999 by Mr. V. Danilov-Danilian, the Chairman of RF State Committee on the Environment Protection, and Mr. Y. Evdokimov, the Governor of Murmansk region. According to this document, MT ASCRS was designed and created as a territorial subsystem of USASCRS (the Unified State Automated System of the Control over the Radiation Situation).

The first stage of MT ASCRS was completed by December 22, 2000; the second stage is to be completed in 2002.

The Murmansk DHMS, as a territorial structure of the Federal RF Service on HydroMeteorology and the Environment Monitoring, is responsible for performing radiation monitoring within the Kola Peninsula and the surrounding water areas.

The first phase of MT ASCRS presently accepts data from the following information sources:

- Murmansk DHMS (exposure dose rate, integral β-activity of radioactive aerosols and depositions, weather data needed for mapping the current radiation situation using GIS of MT ASCRS);
- data on exposure dose rate from ALNOR automatic sensors;
- Information-analytical center of Kola NPP;
- USASCRS Federal Center (exposure dose rate data for Karelia, Moscow region and Leningrad region).

Data are communicated in keeping with a schedule coordinated with every source of information. Data are received in around-the-clock automatic mode.

In USASCRS present-day GIS-technologies use ArcView 3.2, which includes methods of geographical information collection, storage, analysis and mapping based on the interactions of numerical data with their spatial location.

The information used in the GIS-unit is subdivided into two groups: “primary data” and “secondary data”. The first group includes on-line monitoring data: synoptic data and parameters of the radiation situation. At the output are obtained: different maps, plots, charts and table information.

The secondary data reprocessing includes a complex analysis of dot- and areal- pattern information. Using these data, one can generate reports on the radiation situation for a month or a year, obtain detailed reference information on a sensor of interest, etc.

At present MT ASCRS makes it possible to ensure on-line support of both public authorities and the population with reliable information on the current and expected radiation situation, and serves as an information basis to create recommendations for territorial bodies when making decisions related to the radiation safety.

In addition to Murmansk DHMS, other structures of Murmansk region such as: the Committee for Natural Resources, Central Directorate of Civil Defense and Emergency Situations and State Sanitary and Epidemiological Inspection Center, also possess MT ASCRS “on-line” data.

To create full-value territorial ASCRS, one needs to take into account the following circumstances:

- At present the radiation situation in Murmansk region is under the monitoring of 15 laboratories (including three laboratories of state supervisory bodies and 12 departmental laboratories). However, the lack of common methodic basis of studying and processing the results reduces the efficiency of the radiation monitoring;
- Legal matters related to the territorial center financing remain unsolved. To maintain the center created on the base of a federal enterprise, funds of the local budget cannot be used;
- Attraction of foreign investments is an appreciable funding source to support the ASCRS creation. However, the process is restrained for the lack of legal basis for radiation situation data exchange matters between Russia and the concerned foreign countries; and

Still-to-be solved legal issues regarding information communication from departmental ASCRS to territorial ASCRS.

3.3. Contents and Generalized Tasks Related to the Creation of a System of Ecological Monitoring in Regions Involved in NS Handling after the Decommissioning

The ecological monitoring system is developed for purposes of ensuring information-analytical support for regional authorities, regional branch centers involved in NS utilization (of both Minatom and Rossudostroenie) and the concerned enterprises. The system is dealing with the information related to environmental protection and ecological safety of the population in cases of both normal and off-normal operation of enterprises.

Thus, the system of ecological monitoring consists of the following components:

- branch on-site data collection (local monitoring);
- collection, analysis and generalization of the data of environmental monitoring carried out by other departments in regions of branch enterprise locations (local monitoring), of systems of territorial ecological monitoring (RF subjects) and of generalized data of federal departments authorized in the field of environmental protection.

To attain the above goal, the following tasks should be solved:

- Inter-departmental monitoring (control) over the process of environmental contamination (control of effluents, releases, other paths of chemical pollution and radioactive contamination of the environment in locations of enterprises involved in NS utilization);
- Centralized communication of the data from the departmental monitoring system within the framework of the Unified State System of the Ecological Monitoring (USSEM);
- Collection, analysis and systematization of the data of other departments performing monitoring (control) over the process and indices of environmental pollution and contamination, and public health in areas (RCA) and regions (PF subjects) of the branch enterprises with consideration for previous radiation accidents and other emergencies;
- Registering and monitoring of the territories that are polluted and contaminated due to the operation of branch enterprises, and of the work on their decontamination and rehabilitation;
- Objective appraisal of the impact of the branch enterprises on the environment and population health, including an integrated estimation of risks resulting from the enterprise operation. A comparison with other technogenic risks resulting from the

presence of pollutants from other branches of industry and agriculture located in the region; and

In a case of emergency (with ecological implications) at enterprises of NS utilization or in areas of NS basing, ensuring information and analytical support for leaders of the branch and enterprises.

With consideration for the above tasks, the System of Regional Ecological Monitoring (SREM) is to be determined as follows:

> “SREM is an information-analytical system of collecting, processing and presenting the results of observations, estimations and forecasts of negative consequences in the environment and the population health resulting from the operation of enterprises involved in the process of NS utilization. The SREM also allows for comparing these data to the impact of other technogenic factors”.

When creating departmental SEM (task 1), the following issues are worthy of consideration. The process of NS utilization became especially pressing in the course of the last decade. Earlier, no automated system of environmental impact monitoring at installations dealing with NS building and operation was presumed necessary. After transferring the process of NS utilization to Minatom, which acquired important experience in operating such installations within the framework of its own structures, the task of creating an automated ecological monitoring system can be resolved. In principle, the issues of radioecological monitoring have been solved successfully at Minatom installations in operation. However, because of the uniqueness of the NS utilization process, the key points and methods of control (with consideration for the available financial resources and social matters, i.e., PR) should be properly determined.

It is worthy of notice that the issues of confidentiality and restrictions are still important when dealing with the data related to NS utilization. Moreover, only experts are able to estimate adequately incoming primary information. With consideration for all this, the development of a hierarchic data communication system in a «bottom-up» way is advisable. In this manner, on the one hand, no excessive (or confidential) information would be communicated, and, on the other hand, the incoming information would be adapted for a rather large circle of specialists. To select and adapt the data communicated to upper levels, appropriate schedules and software should be developed to communicate and receive messages, and provide for storage, processing and presentation using the facilities of ecological monitoring centers.

To solve task 2, it is necessary to develop schedules of data communication within the framework of USSEM as well as to obtain appropriate hardware and software.

An important amount of the information related to the current state of the environment and the resulting risks that is needed to solve tasks 3 and 4 can be obtained from reports of other departments, such as: State Committee on Statistics, Ministry of Natural Resources, Roshydromet, etc. Regarding this block of information, there are few possibilities for modifying the existing schedules and forms of presenting the data. In such a case, special software to translate information as well as appropriate formats for software of ecological monitoring centers should be created.

Considerable amounts of environmental data can be obtained by analyzing research literature. Such data should be treated analytically, and appropriate methods and facilities for their storage and presentation in electronic form should be developed.

To solve task 5, an analysis of already-available and current documentation (expert-analytical maintenance) is necessary. In this case also the collection and analytic treatment should be scheduled, and methods of data communication and reception as well as those of data storage and presentation in electronic form should be developed.

When solving the task 6, not only data on the initial status of permanent and potential sources of radioactive contamination and chemical pollution of the environment are necessary; but also appropriate facilities for on-line analysis and forecasting of the situation with a possibility of their presentation using computer programs.

Thus, to create SEM, the efforts should be concentrated on the following basic lines:

- Design of systems for receiving and communicating primary ecological information with consideration for already available analytical systems.
- Development of schedules, formats, facilities and methods of data communication as follows: enterprise → branch regional information center → Situation Crisis Center; branch regional information center → regional authorities.

Development of software and databases for receiving-communication, storage, processing and presentation of information with consideration for peculiarities of operating both the systems already available and those under creation.

Organization and information-technical support for the work of expert groups and centers of technical support in a case of emergency (except for the "acute" stage of accidents).

3.4. Basic Functions of the System of Ecological Monitoring (SEM)

The system of ecological monitoring includes the control over all sources of chemical, thermal and radiation pollution of the environment. In one way or another, the enterprises of Minatom of Russia are sources of the above pollution and, quite often, of specific types of pollution (radiation contamination, particular chemical pollution). NPP are responsible for thermal pollution of the environment.

To obtain an objective pattern of the impact of NS utilization enterprises on the environment at a level of branch ecological monitoring, control over all pollutants and contaminants (with consideration for specific features of every enterprise) for every source and every environmental component is necessary. In addition, control over environmental agents, which determine migrations of pollutants and contaminants in the environment (atmospheric transfer, behavior in water media, soil migration, etc.) is required. Thus, the ecological monitoring consists of:

Monitoring over sources;
Monitoring over agents of migration; and
Monitoring over the state of the environment components.

Principal institutions and services, which collect data on the radiation contamination and chemical pollution of the environment at territorial level (i.e., carrying out “local monitoring”) are listed below:

Special services attached to enterprises. They include:

laboratories (departments) of environmental protection;

laboratories (departments) of external dosimetry (LED), which perform both the radiation and chemical control over the environmental components within the buffer area and the radiation control area of enterprises[1];

services of enterprise workshops (departments), which carry out control over radioactive releases (laboratories of radiation safety departments), chemical releases (laboratories of chemical workshops), and organic and chemical substances (laboratories of environmental monitoring).

[1] LED of many enterprises perform also the control over specific chemical pollutants in the environment.

Territorial structures of departments authorized in the work related to the protection of both the environment and human health. These are:

- industrial and sanitary laboratories of Sanitary and Epidemiological Services of Gossanepidnadzor (control over releases and effluents, control of foodstuff within the BA and RCA, of drinking water supply sources, etc.);
- laboratories and weather stations of Roshydromet (monitoring of the atmosphere, surface waters and soils);
- laboratories of territorial bodies of Ministry of Natural Resources (monitoring of the atmospheric air, forests, lands, subsurface, surface and ground waters, and biota);
- territorial structures of Ministry of Agriculture, State Committee on Land Resources, State Committee on Fishery.

Thus, SEM uses principally the information obtained by the above-mentioned services and institutions, which cover all types of monitoring. However, in individual cases, regional centers should initiate special activities to obtain information needed to solve their specific tasks.

3.4.1. Control over Radiation Contamination of the Environment

The control over radioactive releases into the environment resulting from the operation of both Minatom and Rossudostroenie enterprises is well established. There is a good foundation to perform local monitoring, a well-organized system of data collection, analysis, generalization and communication at the federal level, and a developed standard base, which makes it possible to estimate the radiation impact on both the environment and the population health.

If considering the radiation monitoring only, the data received by enterprises in the course of their scheduled radiation dosimetric work constitute the information basis for regional SEM.
In the course of the radiation monitoring the following are controlled:

- gamma dose rate at the enterprise site, in BA and RCA;
- density of beta-particles, alpha-particles, neutrons and other ionizing particles;
- radioactive releases into the atmosphere: control over specific activity and isotopic composition of gas-aerosol releases, and control over flow rates through ventilation systems;
- effluent discharge: control over both the specific activity and flow rate of discharged liquid wastes;
- concentrations of radioactive substances in the environment media (usually in units of measuring specific activity), and soil contamination density; and
- annual effective dose.

The schedule of the radiation control (i.e., extent, type, periodicity, registration and order of recording the results) is organized in keeping with regulatory documents in force.

To obtain these data at departmental regional centers, one needs to determine (in a special document) the schedule of data communication by enterprises in cases of both their normal operation (at least once every three months) and off-normal operation (as new information becomes available).

To receive comparative estimations of the existing levels of the radiation impact on the environment, allowable levels and control levels of the radiation impact are to be developed at every enterprise (see chapter 13 of Basic Sanitary Rules of Ensuring the Radiation Safety (BSRERS)-99). The order of their creation and approval is also determined in the above document. The value levels are set in keeping with such regulatory documents as Regulation Safety Standards (RSS) -99 and Sanitary Rules (SR) of NPP-88/93, with consideration for limitations in their application.

Particular attention should be concentrated on objective appraisal of the radioactive contamination characteristics in BA, RCA and the site of enterprises resulting from their previous defense activities and on the contamination impact on the environmental components and the population health.

In regional SEM of regional authorities, the data of radiation monitoring received by enterprises should be supplemented by the information of territorial services of the departments authorized in environmental protection.

3.4.2. Control over the Environment Pollution by Harmful Chemical Substances

In general, chemical monitoring in the environment is similar to the radiation monitoring, and within the framework of SEM the chemical monitoring data are organized in similar way. However, a specific issue is worthy of consideration: at present the system of chemical monitoring is not elaborated in such a detailed and logical way that the system of radiation monitoring, which can result in the incompleteness (in some cases) of chemical information. Inconsistency is one of the main problems of the control over harmful chemical substances.

When considering indices of the environmental pollution standardized in Russia, problems persist not only in the area of control device availability but also in the ideology of setting standard values.

Every possible official information on releases-effluents of harmful chemical substances, waste accumulation and concentrations of chemical pollutants in the environmental media should be included into the departmental SEM of regional level. But because of the above-mentioned circumstances, individual characteristics for some indices may remain incomplete.

In addition, because of an important contribution of harmful chemical substances into the environment due to the operation of the branch enterprises, which use traditional technologies (thermal power plants, stock of cars, etc.), the separation of their share from that of base industries of the branch is advisable.

3.4.3. Computer Simulation

Within the regional departmental SEM, it is wise to possess elemental models based on the data related to emergency situations that have occurred earlier at similar-type enterprises (in the framework of the database on NS utilization). SCC of Minatom should become the basic center of computer simulation, assisted by technical support centers. The SCC should possess the following mathematical models for chemical and radioactive substances:

- models of admixture dispersion in the atmosphere;
- models of admixture dispersion in open water bodies;
- models of pollutant and contaminant migration in the soil;
- models of underground water pollution and contamination, and models of pollutant and contaminant migration via groundwater;
- models of pollutant and contaminant migration in surface ecosystems;
- models of pollutant and contaminant migration in water ecosystems;
- models of pollutant and contaminant migration in the subsurface;
- models of intake and accumulation of pollutants and contaminants in the human body; and;
- models of calculating the dose impact on the population (for radioactive substances, effective doses are used; for chemical pollutants, their analogues or risk estimations are employed).

The mathematical structure of initial models should make it possible to obtain the result of simulation using the software of information-analytical centers.

During the initial stage of work, one should use the so-called “official” models, i.e., those recommended by competent organizations (RNCRP, UNCEAR, IAEA, WHO, et al.), as well as models in the form of manuals, instructions and recommendations. For parametric identification of models, the use of recommended values of parameters is advisable at the first stage. As new data become available in the course of generation, use and improvement of SEM databases, specific values typical for individual regions where the concerned enterprises are located can be used. Work on adaptation of models with stationary source (case of normal operation) and momentary source (case of off-normal operation) to areas where individual enterprises are located is also important when performing simulation. Issues of parametric identification of models dealing with migrations of pollutants and contaminants in the environment are in close interaction with the tasks of monitoring over the agents, which influence and/or determine the processes of pollutant and contaminant migrations.

3.4.4. Comparative Analysis (Integral and Complex Indices)

When comparing the contribution of enterprises involved in NS utilization to environmental contamination with other industries of the region, the resources of the Regional Center of Ecological Monitoring attached to regional authorities are best suited.

There is a commonly used normative approach, which consists of an estimate of the technogenic impact from the viewpoint of conformity of release-effluent and the environment quality parameters with hygienic and/or ecological standards in force[2]. But if using this approach, in a case of exceeding standard values there is no way to assess the risk of pollution and contamination for the human health and/or ecosystems from a quantitative standpoint. The only conclusion that can be reached in such a case is establishing the fact of apparent potential risks of negative consequences.

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[2] At present the system of *ecological* standards of the environment component quality is not created yet in Russia, except for the quality standards applied to water reservoirs important for fish industry.

To estimate the impact of radiation and other agents on the environment and the population resulting from Minatom enterprise operation, one can use both the normative approach (commonly used in Russia when controlling releases-effluents) and risk assessment methods (being introduced vigorously into managerial practice in the course of recent years).

Risk assessment methodology recommended by both the Ministry of Health and the State Committee on Ecology of Russia (the institutions authorized in the matters of the environment and population health protection) represents an up-to-date method to estimate the impact of technogenic factors on the environment and population health. The methodology is recommended as a foreground one to estimate the risks of the environmental contamination impact on the population health[3]. The value of risk represents a criterion when performing comparative quantitative characterization of the impact of different anthropogenic factors, which also differ from each other in medical and biological effects. The assessment of risk is performed with consideration for all paths (inhalation, ingestion, per cutis) of pollutant and contaminant intake into the human body from the affected environmental media (water, air indoor and outdoor, soil, foodstuff, etc.).

The application of a normative approach in combination with the risk assessment methodology makes it possible to obtain a many-sided picture of the impact of the branch enterprises on the environment and to estimate their contribution into the integral risk of the environmental contamination to human health (Table 3.1.). For most of the branch enterprises (including those of the base industry), one can find similar enterprises of other industries and perform a comparative analysis. A comparative analysis of Minatom of RF, as a whole, with other branches of industry from the viewpoint of the technogenic impact on the environment would be appropriate.

[3] see the Decree №25 of the Chief Sanitary Inspector of RF of November 10, 1997 and the Decree № 03-19/24-3483 of the Chief State Inspector on the Environment Protection in RF of November 10, 1997 "On the Use of the Risk Assessment Methodology to Manage the Quality of the Environment and the Population Health in the Russian Federation".

Table 3.1. Current Ecological Tasks, Methods and Indices Used within the Framework of the System of Ecological Monitoring under Creation

Ecological Task	Applied Methods	Assessment Level	Indices
Estimating the level of the technogenic impact on the environment and determining the position of the branch enterprises among other sources of technogenic loads	Normative approach (commonly used); Integral approach	Local Regional	Real release (effluent discharge) – standard value relationship Normalized release (effluent discharge) of pollutants & contaminants Contribution of the branch enterprises in the integral territorial (normalized) release (effluent discharge) Absolute (amount of discharged effluents) and relative (fraction of polluted & contaminated waters in the integral fresh water amount used in the branch) indices of water use and land use
Estimating the level of the environment contamination & pollution and/or degradation and defining the contribution of the radiation factor among other sources of the environment pollution	Normative approach (commonly used); Integral approach	Local Regional	Relationship: real concentrations - standards (or background values) in the environment media, foodstuff, drinking water Integral quality indices of the air, surface waters and soils
Estimating the risk of the impact on the population health and ecosystems; determining the contribution of the branch enterprises (comparative assessment)	Risk assessment methodology	Local Regional	Risk values for carcinogens Toxicity potential for system toxins
Estimating the population health in areas of the branch enterprise location	Comparative medico-ecological approach	Regional	Integral indices of the population health (lifetime, mortality, et al.)

The results of complex assessment of the impact of the branch enterprises on both the population health and the environment (in the form of integrated indices or estimates) at local and regional levels allow for obtaining an illustrative pattern of the ecological situation in areas of the branch enterprise location.

The following indices are to be considered as generalized characteristics of the quality of the environment media and the population health:

- quality of surface waters from the standpoint of their chemical, radioactive, et al. pollution and contamination (classification in force);
- air quality in the urban environment (classification in force);
- drinking water quality (the fraction of samples which do not comply with the standards in force, comparison with average values in Russia);
- foodstuff quality (the fraction of samples which do not comply with the standards in force, comparison with average values in Russia);
- population health indices (integral health index, comparison with average values in Russia);
- health risk level due to the environmental pollution and contamination; and
- characteristics of territorial water balance (with deficit, without deficit).

3.5. General Requirements to the System of Radioecological Monitoring (SREM)

In keeping with the requirements of Radiation Safety Standards (RSS-99) [3.15], the principle of non-exceeding permissible limits of population exposure doses from all radiation sources is the foundation for making decisions on population protection against radiation hazards under both normal and off-normal operating conditions of enterprises. Neither accumulated nor predicted exposure doses can be measured directly; they represent the result of an integrated estimation based on the generalization of both the current information and forecast calculations of expected implications.

Consequently, when creating and operating SREM, the following principles should be considered as basic ones:

- ensuring sufficiency of the information to be presented at the output;
- efficient reaction of SREM on the radiation situation variations; and

SREM operational reliability and adequacy of the results.

Work on SREM development should be based on the regional infrastructure in force (i.e., administrative, technologic, telecommunication, etc. infrastructure). The above principles should be realized on condition of acceptable SREM costs.

Using these principles, the basic requirements to SREM subsystems (the information subsystem, the analyzing subsystem and the generalizing subsystem) are determined.

SREM is built using the hierarchical principle and consists of the following base subsystems:

- information subsystem of surveying and measuring the radiation situation parameters;
- analytical subsystem of collecting, processing and analyzing primary results, data transformation and coding to communicate to upper hierarchical levels;
- generalizing subsystem for estimating the state, preparing proposals on alternative responses in a case of changes in the situation, calculating necessary resources to store information; and
- subsystem of internal and external links, and of data and instruction communication.

In keeping with the “sufficiency principle”, the information subsystem should be based on optimum combination of the degree of responsibility with volumes of measurements performed by stand-alone (automated) stations located in the region, by stationary radiological laboratories and by mobile laboratories of the radiation situation analysis.

The analytical subsystem consists of many centers, which collect, treat and perform express-analysis of primary data obtained from the information subsystem organized in the form of a local network. Here also the information is transformed for purposes of its subsequent communication to upper hierarchical ASCRS subsystems or to the neighbor centers of primary information collection. Centers of the analytical subsystem should be able to receive information from specialized or departmental systems of the control over the radiation situation.

The “reliability principle” requirements and, in particular, those of the adequacy of the results of the radiation situation monitoring, determine the main function of the generalizing subsystem. The main body of SREM is the center of generalizing information (territorial information analytical center) destined to:

- estimate the radiation situation at both the regional and the local level,
- confirm the adequacy of the results of estimating the radiation situation,
- prepare proposals on alternative responses in a case of changes in the situation,
- calculate the needed resources,
- store the data, and
- perform other functions (e.g., dispatcher distribution of algorithms when operating centers of primary information collection).

Starting from the principle of "acceptable costs", the system of links and the data transmission should be generated at the first stage using switched lines of automatic telephone systems. As a rule, only closed-switched telephony is available at enterprises. By this is meant that there is neither an exit to regional administrative centers nor the possibility of direct inquiries of information subsystems by analytical centers. This problem can be resolved through data communication from enterprises in file-form via electronic mail. Provision should be made for message generation in cases of both normal and off-normal mode of operation (in the latter case, larger data amounts should be communicated). To improve future system reliability, telecommunications should be duplicated by a cellular communication system. In the event that telephone service is lacking, radiotelephony should be used.

Further refining of SREM structure at specialized, departmental and territorial levels will constitute the subject matter of an independent work if the whole concept is approved in general.

3.6. Structure of Regional SEM

Recommended SEM structure, similar to both the Murmansk region and the Arkhangelsk region, is demonstrated in Figure 3.3. The system description is given below, starting with the bottom level.

3.6.1. Monitoring at Enterprise Level

In our opinion it is at the enterprise level that the most comprehensive control over the process of NS utilization should be carried out. Here, basic information on releases and effluents for all operation modes can be obtained, including the case of emergency. Starting from peculiarities of

NS utilization, one can distinguish the following processes, which can lead to worsening of the radiation and/or ecological situation, and, consequently, should be controlled:

SF unloading from the decommissioned NS and SF putting in containers;
SF storage and transportation;
LRW and SRW treatment and storage;
Waterborne storage of NS and three-compartment units; and
Chemical contamination when NS dismantling.

At the current stage of automatic device development, the automation of every parameter listed in standard documents (referred to the processes to be controlled) cannot be performed. Principally, the control over gamma dose rate is most important since it is this factor that determines dose loads on both the personnel and the population in most cases. The control over radionuclide concentrations in gas-water medium is also required, since it makes it possible to reveal trends in the radiation situation worsening at early stages. The control over the above parameters can be automated using the available (already created) measuring facilities.

The control over effluents discharged by enterprises is advisable using submersible scintillation detectors, which operate under spectral mode. In our opinion, this is the only way to detect (at a level of natural background) the contribution of technogenic radionuclides (^{60}Co, ^{134,137}Cs) in the water medium. Such a type of automatic control can be realized using present-day facilities.

Other radiation parameters (to be controlled in keeping with RSS-99) as well as chemical pollutants should be measured using portable devices or in laboratories; the obtained results should be introduced into databases of local (i.e., at the enterprise) Information-Analytical Center (IAC).

With consideration for peculiarities of the utilization process, new types of automatic control are advisable. By this is meant the control over water ingress into reactor compartments, draft/trim of NS and three-compartment units in waterborne storage, the monitoring of temperature in reactor compartment rooms and of pressure and temperature of the primary circuit coolant. Such types of control will contribute to revealing negative tendencies related to the contact between marine water with contaminated structures and, thus, to potential radionuclide issuance into the water medium.

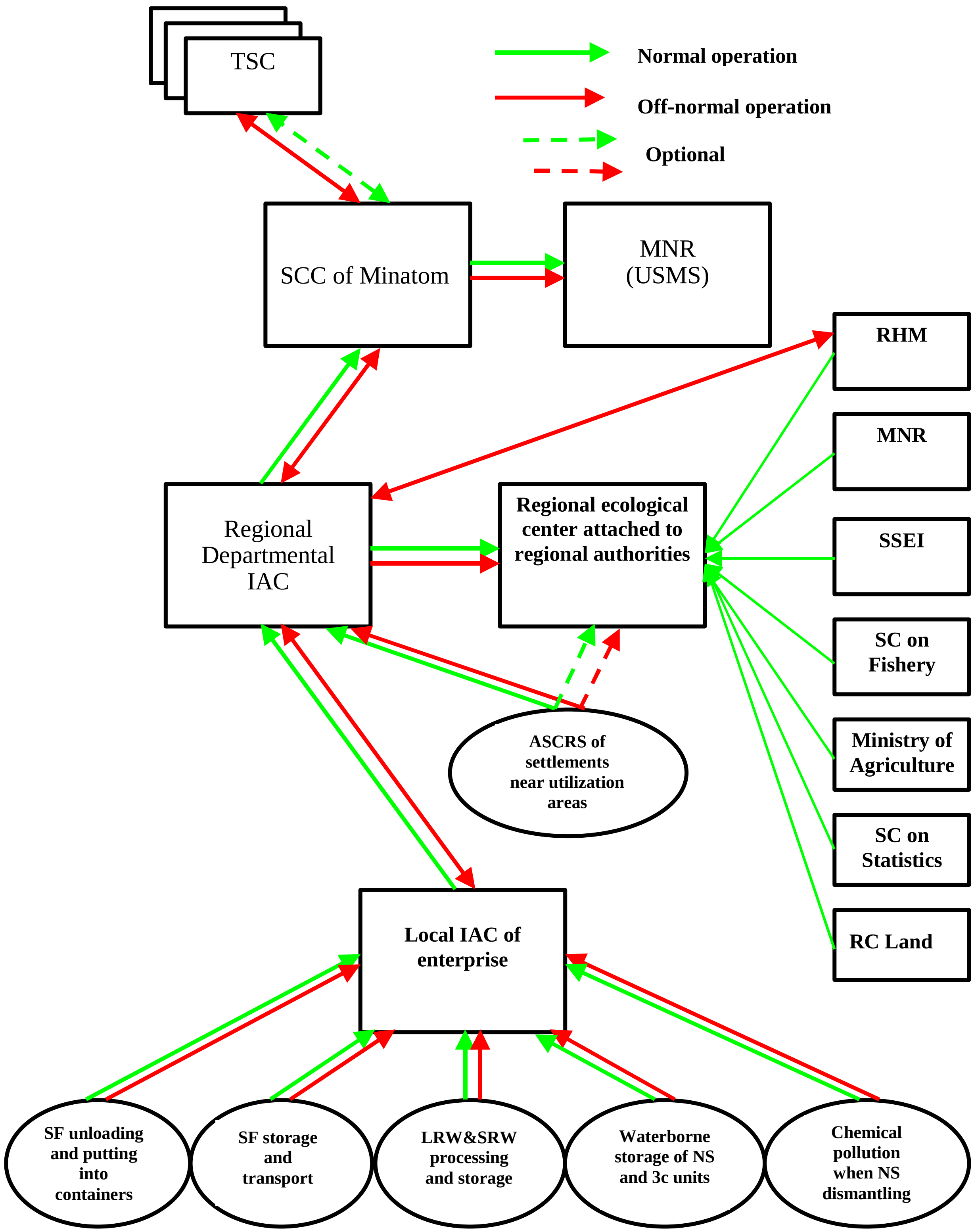

Figure 3.3. Structure of Ecological Safety Management during the Process of the Decommissioned Nuclear Submarine Utilization

The local IAC performs tasks of collecting, analyzing and storing the incoming information as well as its subsequent communication to upper levels. It is worthy of notice that all these data characterize technological processes at “secret” enterprises or at the Navy bases and, thus, are not to be made public. But, on the other hand, the data of the close-to-the-source areas are most informative from the viewpoint of the situation forecast in a case of emergency. Therefore, in emergency situations, these data should be accessible to decision-making structures (regional authorities, committees on civil defense and emergency situation affaires, etc.) and to institutions entrusted with global forecasts of environmental contamination (Roshydromet institutions). Possible ways in solving such a contradiction will be proposed when describing requirements to the information support of the system. However, it should be stressed that the issues related to schedules and amounts of information to be communicated from enterprises dealing with NS utilization under both normal and off-normal operation mode should be worked out in great detail and with consideration for the user.

3.6.2. ASCRS of Settlements in the Vicinity of NS Utilization Enterprises

The ASCRS of settlements is required to control the spreading of releases (sometimes of effluents) beyond the site of “secret” enterprises. It represents an open system where information is accessible for the general public; on the first request, ASCRS data can be made public.
As a rule, during the process of NS utilization the expected radius of hazardous effects on the population in a case of emergency makes up few kilometers at the most. This is the distance at which the nearest settlements are located. One can recommend placing dose rate sensors (few units) along the perimeter of the enterprises in question in direction(s) toward the nearest settlement(s) or at the settlement boundary closest to the hazardous installation. The monitoring can be reduced to measurements of gamma dose rate.

It is worthy of notice that although the ASCRS sensors indicating «normal» radiation background have a favorable effect on the population attitude, in a case of emergency such sensors are able to give only little information. For proper interpretation of the sensor readings from the viewpoint of dose forecast on the population, one needs information on source term as well as a more detailed radiation survey within the concerned territory. To realize such a survey, one needs a special mobile radiometric laboratory attached to the enterprise services. Its' specialists will perform referencing of the coordinates for points of measurements using a GPS satellite system and will transfer the results to both the concerned enterprise and upper structures via radio-communications.

It is recommended to perform servicing of the ASCRS for settlements using the enterprise forces because of the following reasons. First, in some cases settlements in the vicinity of enterprises dealing with NS utilization are Closed Administrative and Territorial Structures (CATS); therefore, no information can be communicated beyond their bounds. Second, with consideration for the enterprise specificity, the best survey results can be obtained by placing sensors along the enterprise perimeter; however, in such a case the data of these sensors can be considered by special services as «secret» ones. Third, taking into account specific features of potential radiation and chemical accidents at NS utilization enterprises, hazardous implications for the population can be expected within the buffer area only; here the control over the ecological situation is imposed on the enterprise. Readings of sensors owned by Roshydromet or other non-enterprise structures outside the buffer area should be taken into account and analyzed at the regional ecological center (see below).

According to the legislation in force, the data obtained beyond CATS boundaries have "open" status and can be communicated without any restriction. However, the problem of ensuring the information safety (from the standpoint of its distortion, blocking or falsification) still persists. When communicating information from CATS, similar problems emerge as in the case of data transmission from enterprises.

3.6.3. Departmental Regional Information and Analytical Center

In Table 3.2 are listed tasks and functions of departmental information and analytical center under both normal and off-normal mode of enterprise operation.

The creation of departmental IAC is advisable because of the following reasons:

Order is needed in the process of data communication from enterprises to SCC and to the regional ecological center following their preprocessing. By this is meant not only the preparation of concluding messages in a unified (for all enterprises) format but also the information “pre-filtering”, i.e., removal of excessive data (case of routine control under normal operating conditions) and of restricted-access data;

Generally, a departmental regional center, at which competent specialists are working, is placed in the immediate vicinity of the enterprises dealing with NS utilization. Therefore, the center experts should be familiar with peculiarities of the enterprise operation. This will relieve the specialists of SCC and of the regional ecological center of the analysis of excessive details; at the same time, if necessary, most detailed information on issues of their interest can be obtained; and

Departmental regional IAC located in towns and possessing better communication facilities can ensure more reliable information protection when transmitting to upper hierarchical levels than in the case of direct data communication from enterprises (there is an additional «network screen», see below). Moreover, removal of “excessive” data when generating messages is a mode of the information protection.

In departmental regional IAC one needs to maintain not only a database on the ecological situation at NS utilizing enterprises but also a «knowledge database». By this is meant the development of an Automated Information-Reference System (AIRS) giving to user the appropriate instrumentation to analyze scientific, legislative, economic, etc. information related to the issues of NS handling after the decommissioning. These issues are considered in more detail in chapter 3.7.2.

In a case of off-normal enterprise operation, departmental regional centers are able to become the most competent and informed information providers to communicate data to upper levels (i.e., to SCC and regional ecological center). Provision should be made for ensuring sufficient information and intellectual resources within departmental IAC to realize (in most cases) information support of decision-making structures. In most hazardous situations an address to information resources of Minatom SCC is advisable.

Table 3.2. Tasks and Functions of Departmental Regional Information and Analytical Center

Task	**Function**
Information collection for every enterprise and data communication to SCC and to the ecological center attached to regional authorities	Information collection from local IAC (at enterprises) in automatic mode in keeping with an agreed schedule & format. Automatic data communication to SCC and ecological center attached to regional authorities and working through of inquires. Updating of reference information for

	enterprises under the control.
Information support of SCC and regional ecological center under “off-normal” mode of the enterprise operation	Notification of SCC and of regional ecological center. Working through of inquires of SCC and regional ecological center under “off-normal” enterprise operation mode. Analysis of the emergency situation and preparing recommendations to regain normal operation state or to eliminate the accident consequences (in a case that this work cannot be performed using the enterprise resources). SCC information resources can be involved. Post-accident analysis, presenting reports to SCC and to regional ecological center.
Preparing and performing emergency-response training and exercises	Development of scenarios and performing emergency-response training and exercises. Analysis of the results and preparing appropriate recommendations related to emergency response at enterprises
Maintaining the “operability” state and upgrading hardware & software	Ensuring “24-hours a day” mode of the center operation. Keeping “up state” of communication lines with SCC and IAC of enterprises. Ensuring information protection. Upgrading hardware and software.

The issues of the information safety in case of “off-normal” operation are most urgent and should constitute one of the basic functions of departmental IAC.

3.6.4. Regional Ecological Centers Attached to Authorities of Murmansk Region and Arkhangelsk region

The creation of ecological centers, in general, and in the Russian Federation, in particular, is a difficult problem, which has not been resolved adequately yet. The reasons are, on the one hand, enormous amount of information needed to perform analysis and, on the other hand, the lack (in most cases) of appropriate computer facilities to obtain these data. The information dispersion over different ministries and departments, which interact poorly with each other, is a further complicating factor. Moreover, at the present time there is no institution that possesses the needed experience and has specialists able to understand such a complicated and multiform problem as the ecological safety in its entirety. In our opinion the task of creating a properly functioning ecological monitoring system can be resolved only in the future. At present, one is only able to characterize the problem in general and to outline few first steps. After that, attention will be focused on the issues of presenting radioecological information as a component needed to perform complex analysis of the ecological situation.

As was mentioned above, the system of ecological monitoring should include at least the following subsystems:

1. "Dynamics of Indices" - the subsystem is designed to receive, analyse[1] and visualize[2] ecological monitoring data:

> of enterprises (under normal operating conditions - "once every three months" data communication mode is sufficient; in a case of emergency – as new information becomes available);
>
> of branch and territorial systems of ecological monitoring as well as of the systems of federal bodies authorized in environmental protection (annual environmental reports).

2. "Complex Assessment" - the subsystem is designed to present information on the ecological situation in areas of branch enterprise location. These data include the results of complex comparative assessment of risks and other parameters of the impact of the branch enterprises on both the environment and population as well as of the integral ecological indices in the region under consideration.

3. "Simulation and Forecast" - the subsystem is aimed at modeling, predicting and supporting the process of decision-making under both normal and off-normal (except for the acute phase) operating conditions at enterprises or in areas of their location.

Starting from the allocation of responsibilities related to the collection of ecological information in RF, regional ecological centers (in addition to the data communicated via departmental

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[1] To compare with standards in force.

[2] Data of laboratory control including data on laboratory parameters.

channels of Minatom, Rossudostroenie, et al.) are to collect data of the following ministerial and departmental subdivisions (at regional level):

- Roshydromet;
- Ministry of Natural Resources;
- State Sanitary and Epidemiological Inspection;
- State Committee on Fishery;
- Ministry of Agriculture;
- State Committee on Statistics; and
- Russian Committee on Land Resources.

Thus, SEM mainly uses the information obtained by the above services and institutions. In principle, these data embrace all types of monitoring; however, in individual cases the regional center itself should initiate special activities to obtain information needed to resolve its specific tasks.

To reach efficient operation of SEM, one needs to develop, coordinate and approve a package of organizational and administrative documents including:

- The order of collecting, processing and presenting information contained in reports of the authorized federal departments and the corresponding territorial structures;
- The order of introducing and correcting the ecological data in regions branch enterprise location, including the results of complex comparative assessment of risks and other parameters of the branch enterprise impact on the environment and the population; and
- The order of interactions with centers of expert support.

Basic functions and main tasks of SEM were stated in Chapters 3.3 through 3.5 above.

3.7. Defining Requirements to Mathematical and Information Support of SEM

3.7.1. Requirements for the Information Support of Local IAC

To perform properly its own tasks, regional IAC should obtain the following types of information via IAC of enterprises:

In automatic mode at a scheduled periodicity:

- Values of technological parameters characterizing safe operation of all potentially dangerous installations at the given enterprise; and
- Data on radiation, chemical and ecological situation at enterprises, within the buffer area and the RCA from automated control systems.

In keeping with the preset schedule:

- Reports within the framework of the State system of registration and control over nuclear materials;
- Reference data on the enterprise;
- Notification in a case of off-normal situation at the enterprise and reports on its current ecological situation;
- Data of laboratory survey over the environment state; and
- On individual demand – additional information.

The creation of local IAC at enterprises will make it possible:

For regional IAC to have access in «on-line» mode to the data which characterize the normal operation of enterprises in order to carry out the control over both the technological safety and the radiological situation;

For local and regional IAC to perform inter-computer data exchange in “file-exchange” mode; and

For IAC of enterprises to have access to informational resources of regional IAC, in particular, to legal DB divisions.

If appropriate, telecommunication facilities between local IAC and regional IAC are available; audio-conferences and videoconferences can be organized.

IAC of enterprise should ensure data collection related to the technological safety and the radiation situation at installations and in RCA from measuring systems of the enterprise, their pre-processing and preparing for further communication to regional IAC. Automatic data collection should be organized in such a way that any possibility of intervention into the system operation (which can possibly result in malfunctions) would be eliminated.

If no automated information-measuring system of the control over technological processes and the radiation situation is available at the enterprise, local IAC should possess special software (to allow for introducing and communicating the required information manually) as well as appropriate organizational support facilities.

In general, the local IAC should ensure interactions between the local network of the enterprise and the information telecommunication system of regional IAC.

The dataware of local IAC is created on the base of routine collection of the necessary data from different subdivisions and information-measuring systems of the enterprise. Data communication to regional IAC in routine mode or on demand should be obligatory for enterprises. The enterprise leaders are responsible for well-timed communication of reliable information. Organizational and legal issues of information exchange between enterprises and corporate structures of the branch, on the one hand, and SCC, on the other hand, are determined in «Regulations on Information Exchange» approved by Minatom of RF in the Order №223-p and put in force on November 30, 1999.

In keeping with the above document, the enterprise is to communicate information, which allows for assessing its state. The information sources are:

Real-time data (or quasi-real-time data) from systems of the control over the radiation and ecological situation (ASCRS);

Data of technologic process sensors (the required information amount only);

Manually introduced data; and

Other data (from other sources) helpful to estimate the situation.

To perform information exchange between the enterprise and regional IAC, a computer-gateway is chosen in local network of the enterprise aimed at receiving information from the enterprise, its pre-processing and communicating to regional IAC in keeping with preset schedules.

Information exchange between local IAC and regional IAC should be realized via a special communication channel. As a reserve, both a dial-up line and a telephone line are provided.

Local network of the enterprise, ASCRS sensors, technological sensors as well as the data introduced manually constitute information sources on the enterprise operating conditions. In general case, information from sensors is available within the enterprise local network; the data are stored in unique format for each enterprise.

Data collection intervals depend on the type of information and the enterprise activities; however, in general no real-time demand is made. Under normal operating conditions it seems sufficient to collect information at about 30-minute intervals. In a case of emergency the interval reduces, whereas the list of parameters to be collected is enlarged. Values for time-intervals and data amounts are determined individually for every enterprise.

An important issue is the separation in time of instances of data-portion communication from enterprises to regional IAC in order to avoid overloading communication lines.
The software of local IAC can be subdivided into two categories:

- General-system and network software; and
- Application software used to obtain, handle, analyze and visualize the data.

General-system and network software should include the following components:

- Operational general purpose systems (of Windows NT or Windows 9x type); and
- Network protocols (of TCP/IP-type).

Application software should comprise:

- Computer facilities for collection, processing, communication and visualization of technological information; and
- General-purpose packages of application software, such as: electronic tables, text processors, document circulation systems, etc.

Issues of protecting the data to be communicated should be worked through individually. All the data coming from enterprises, except for ecological characteristics of the buffer area, are of restricted use; therefore, they should be protected most carefully.

3.7.2. Requirements to Information Support of Departmental Regional IAC

To solve tasks of regional departmental IAC, the following information is needed to ensure its proper operation:

- Current data on enterprises ensuring monitoring of the state of installations under the control;

Reference (conditionally-invariable) data required to analyze the situation and make decisions;

Data on the registration and control of nuclear and special purpose materials; and

Regulatory documents (laws, regulations, standard documents, etc. in the atomic energy field).

All these data should be stored in electronic form within a special databank of the regional IAC.

To perform the above tasks, the development of an automated information-reference system (AIRC) allowing the user to analyze scientific, legislative, economic, etc. information related to the issues of the decommissioned NS utilization is advisable.

The collection, classification and analysis of the information needed to develop real projects of NS utilization represent a rather labor-intensive task. At present no appropriate *methods* are created. In our opinion such data should be unified within a single databank comprising a number of functionally interconnected units. The collected information is necessary, on the one hand, to chose the optimum NS utilization mode and, on the other hand, to ensure safe and efficient carrying out of individual operations, equipment dismantling, RW treatment, packaging and transportation.

The rough scheme of AIRC is illustrated in Figure 3.4. Generally, AIRC consists of three large units: a reference-information system, a unit of data aimed at estimating the radiation potential of every decommissioned NS and a unit for obtaining primary data to develop individual NS utilization projects.

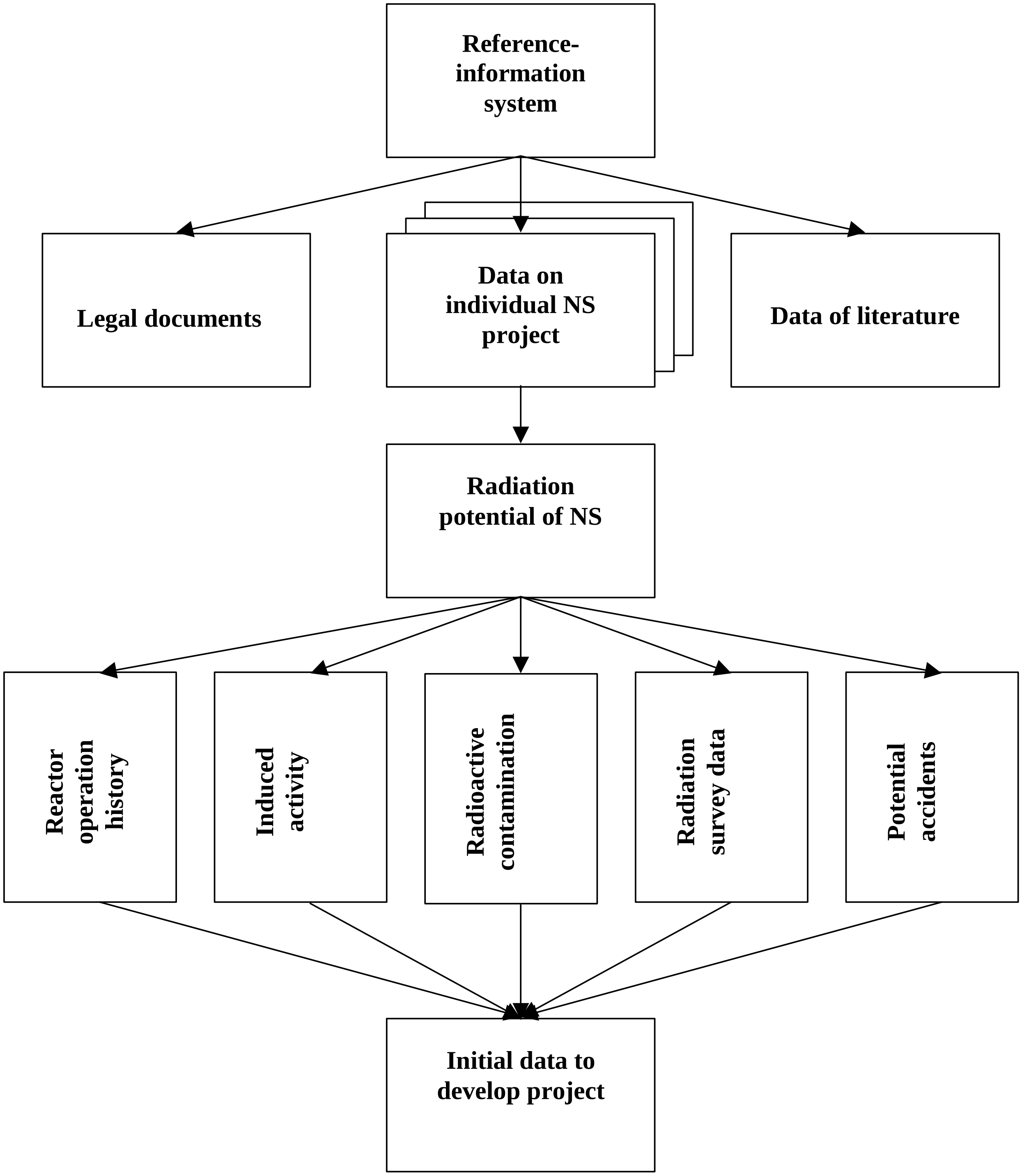

Figure 3.4. Rough Scheme of AIRC Dealing with Utilization of the Decommissioned NS

The first unit contains information related to legislative and standard documentation on NS utilization; data (in the needed amount) on individual NS utilization projects; literature (articles, reports, communications, etc.) comprising Russian and foreign sources.

The second unit includes information that makes it possible to assess the radiation potential of every individual decommissioned NS from the standpoint of work to be realized. It is advisable to include into this unit the history of NS reactor (s) operation at full power, estimates of induced activity in constructions, evaluations of the radioactive contamination and data of real NS radiation monitoring. It also makes sense to introduce estimations of radiation consequences of potential accidents in the course of NS utilization or waterborne storage. The data of the second unit constitute the foundation for the third unit.

The third unit should be able to generate data focused on practical work as well as the data required in obligatory documents, which accompany the utilization process. These are: reports on ensuring the ecological safety at all stages of NS reactor compartment handling, reports on radiological surveys, scheme of response-actions in cases of radiation accidents, etc. Should be accessible: estimations of NS radiation potential changes over time, estimates of the type and composition of RW created, evaluations of the efficiency of decontamination procedures, etc. Most likely, task-level application software should be included into the third unit to obtain calculated estimations and generate thematic reports dealing with above-listed issues.

An independent investigation of a detailed AIRC structure should be conducted if a decision on creating such a AIRC is made.

The departmental regional IAC should possess a general reference system for enterprises created on the base of GIS-technologies. When developing such a system, the following initial requirements should be taken into account:

- Ability to deal with manifold non-structured attributive, graphic and cartographic information;
- Reference of the entire database to common co-ordinates;
- Ability to connect new information units and subsystems with minimum man-hours; and

Porting of the entire subsystem or of its individual components to other computers (including portable ones).

It is suggested that the information unit should include (at least) the following information:

Brief description of the enterprise in question;

General reference data;

Electronic maps of the enterprise neighborhoods;

List and characteristics of "hazardous" enterprises from the radiation or chemical point of view;

Schemes of enterprise sites with indication of buildings and installations and their brief description;

Schemes of BA and RCA and location of their bounds;

Database on settlements within RCA with indication of the number of inhabitants;

Program of response actions aimed at protecting the personnel and population against radiation accidents and their consequences (program of emergency response actions);

Schemes of radiation monitoring systems and their description; and

Information on ecological impact of enterprises on both the environment and the population.

In regional departmental IAC the data of different "confidentiality" level and of "secrecy" level should be processed and communicated:

"open" information to be published in "open" sources;

"confidential" information with a status of official, commercial and other secrecy; and

information of "State secret" status.

In this connection, the issues of ensuring the information safety are rather important. Therefore, the corresponding organizational, legal, program and technical solutions aimed at protecting all types of information from unauthorized access should be ensured.

3.7.3. Dataware of Regional IAC Attached to Regional Authorities

Regional IAC should be equipped with information systems to ensure ecological monitoring and the control over sources of radiation contamination and to support the process of making decisions related to the radioecological safety, the environment and population protection.

When creating dataware for regional IAC, the following basic tasks should be resolved:

- diagnostic assessment of the current state of the radioecological situation in areas where radiation-dangerous installations are located, within their BA & RCA;
- identification and analysis of the areas of particular radiation hazard;
- detection of radiation-dangerous installations whose activities result in worsening of the radioecological situation;
- revealing of tendencies in the radiation situation evolution;
- optimization of the radioecological monitoring network;
- determining most vulnerable cohorts of the population in a case of the radiation situation worsening; and
- estimate of the efficiency of both actions and strategies aimed at minimizing negative consequences of the radiation situation worsening.

The above tasks should be solved on the base of GIS-technologies via:

- processing and analyzing spatial data;
- data presentation in the form of maps, diagrams, plots and schemes;
- interaction with other information systems and technologies (databases, simulation and forecast models, expert systems); and
- creation of high-quality map products.

For informational GIS, the following base types of information should be used:

- cartographic materials;
- radioecological monitoring data;
- data of institutions of branch ministries and departments including the data of branch cadastres (inventory of land-, forest-, water- resources, etc.); and
- state statistical data, legal and standard documents.

Cartographic Information. Cartographic information is to ensure sufficient detailed and accuracy of the data; it should contain all information needed to support the decision-making process and be represented in formats allowing information exchange between subsystems of different levels (including USASCRS and USSEM). In keeping with the RF legislation, digital maps are to be licensed and possess all required certificates.

Geographical bases should contain standard general geographical layers: administrative region boundaries, settlements, relief, water sources and hydraulic structures, industrial, agricultural, institutions of social and cultural implication, road network, vegetation and soils, legend and other elements.

Thematic layers should contain: radiation-dangerous installations, sanitary control areas of inhabitable zones, survey network and sampling stations by departmental subsystems and structures of ASCRS, network of weather and hydrologic stations as well as other layers (especially determined and agreed).

Thematic Information of the Radioecological Monitoring. This information is aimed at ensuring information support of models and expert systems.

The control over radioactive releases in the air and effluents into water sources is carried out using resources of enterprises. The information on sources of the radioactive contamination supplemented by data of other departments (HydroMeteorological Service, Ministry of Agriculture, Ministry of Public Health, Ministry of Natural Resources, et al.) is used to assess the impact on both the population and the environment and to identify its tendencies.

Statistical and Standard and Legal Information. Creating databases within regional IAC attached to regional authorities, involves statistics aimed at evaluating natural-resource and socio-economic complexes (first of all, population census data, public health indices, maintenance supply information). Most statistical data needed to create databases can be obtained from statistical institutions of the state, branch ministries and departments keeping statistics.

A list of standard-legal documentation is an obligatory component for all databases of this level. It includes standard, legal and administrative documents of federal level as well as regional and departmental legal documents.

3.7.4. Simulation of Radioactive Substance Spreading

Computer systems based on GIS-technologies that simulate the spreading of radioactive and chemical substances are indispensable when making decisions in a case of emergency. Considerable progress has been made toward the creation of such systems in the past few years.

Among software developed in the Russian Federation the following systems should be pointed out.

RECASS-NT Decision-Making Information Support System to Forecast and Analyze the Radiation Situation (Developed by FIAC of Roshydromet, RPA «Typhoon»)

The system operation is organized using the «client-server» principle; clients can interact with the system using both “local” and “remote-access” mode. All calculations are performed on the server; client objects interact with the user. The information basis of the system consists of a base of on-line data, a base of system data and a base of calculation results. The system allows for performing concurrent calculations (including calculations for the same accident using different scenarios).

The main components of the system are listed below [3.16]:

- Integrated databank (DB);
- Operational system – task manager, servers of access to DB;
- Functional subsystems of the control, forecast, analysis and estimations;
- Telecommunication subsystem; and
- Client subsystem (installed as “local” or “remote” terminal).

In principle, the implementation and application of RECASS system in information and analytical centers of USASCRS can resolve issues of informational interactions between specialized, territorial and departmental USASCRS subsystems and the tasks of decision-making in a case of emergency.

In keeping with an instruction of Rosenergoatom Concern, in 2001 the system “RECASS NT” is to be installed at all Russian NPP except for the Leningrad NPP and Bilibino NPP.

Taking into account the specificity of the Northwest region of Russia, one can point out the following shortcomings of the system:

- The system is rather sophisticated and imposes heavy demands on user professional skills;
- When using “remote terminal” operation mode, high-quality communication lines are necessary;

The program calculates only release parameters, i.e., radionuclide concentration in the cloud, dose rate from the cloud and fallout, soil contamination, etc. The system is unable to calculate in an explicit form predicted doses for the population, i. e., the most important parameter when making decisions; and

The specificity of calculating releases from sources close to ground level is not taken into consideration.

Admixture Transfer Model in GIS ASCRS -«Source» State Institute of Applied Ecology

The mathematical model of admixture transfer in the atmosphere is based on the semi-empirical equation of turbulent diffusion (gradient transfer theory). The program «Calculations of the Extent of Accidents at Radiation-Dangerous Installations» was developed by specialists of Military University of Radiation, Chemical and Biological Protection of the RF Ministry of Defense in order to solve tasks of on-line estimations of the radiation situation if reactors of both VVER-type and RBMK-type collapse [3.17]. At the output, the following information is obtained:

Matrix of dose rate expectancy resulting from the radioactive contamination within the radioactive trace; and

Maximum dose rate values at a point with preset coordinates.

The ability to perform automatic loading of weather data on demand from DB of Roshydromet can be considered as an advantage of the program. The program’s shortcomings are potential application to reactor accidents only and insufficiency of output information to analyze decisions regarding population protection.

Computer System NOSTRADAMUS of Simulating Radioactive Substance Spreading of Nuclear Safety Institute of the Russian Academy of Sciences (IBRAE RAN)

The system can be applied in any case of radionuclide release but is especially focused on atomic energy installations. The system comprises a databank of possible scenarios at nuclear reactors (release rate, potential nuclide composition and dispersion composition). At the output are obtained radionuclide concentrations in surface air, density of depositions, and dose rates from different radionuclides via different paths.

The following models of processes are integrated into the package [3.18]:

Reconstruction of parameters of the boundary layer using surface air measurements (wind, wind shift, turbulence coefficients);

Lagrange 3D model of admixture transfer and diffusion in the atmosphere;

Nuclide decay chains;

Exposure from volumetric source; and

Dose load models with consideration for radionuclide type and the impact paths.

It is possible to connect a cartographic substrate with demographic data, which allows for dose calculation for the population, as applied to selected settlements.

Although the package comprises the latest advances in meteorology related to the issues of admixture dispersion in the atmosphere, difficulties emerge when presetting the needed amount of initial meteorological data. The package is rather sophisticated and is to be used by professionals. Its advantages are most apparent when calculating admixtures for long distances over prolonged periods of time (but such circumstances are very improbable in cases of potential accidents at installations dealing with NS utilization).

Electronic Program Complex "Zone" of SC «LenEcoSoft», St. Petersburg, Used in SRC RIAR

In "Zone" EPC 3D trajectory hydrodynamics models are used, which make it possible to consider the effects of buildings and other constructions on the distribution of radionuclides in the air and on-site. EPC "Zone" ensures [3.19]:

Calculation of radionuclide substance transfer in the atmosphere at a distance up to 256 km;

Calculation of fields of weather parameters (3D-fields of wind speed and turbulence characteristics);

Consideration of the effects of the territory build-up, orography, ground type, location and rate of source term, and atmospheric precipitation on the dispersion process;

Taking into account physical effects of the atmosphere (barrier layer, daily variations, breeze circulation);

Calculation of fields of concentration and the intensity of radionuclide substance fallout from the chosen ensemble of different configuration source terms;

Solution of inverse tasks to identify sources and their parameters using the results of observations;

- Carrying out climatic calculations, i.e., calculation of fields of average and background concentrations of radioactive substances for a month, a season or a year; and
- Calculation of the contaminated area resulting from accidental releases of radioactive substances.

EPC “Zone” is able to describe the specificity of releases of installations dealing with NS utilization; however, it is unable to calculate in an explicit mode the expected doses on both the personnel and the population.

Program Complex «GRANAT-UNIVERSAL-NUCLIDE» to Calculate the Contamination of the Atmospheric Air by Chemical & Radioactive Substances on the Base of BRD-86 and AR-98 (RPA Granat, Moscow)

The algorithm for calculating the atmosphere contamination using «Granat» and «Universal» program modules is based on the “BRD-86” standard document (put in force in the former USSR). The complex gives the user the following possibilities [3.20]:

- Calculations with and without consideration for the effects of industrial and residential areas in the surface layer of air at different levels from the earth surface;
- Operation with source terms of 4-types (point, linear and areal sources of 2-types);
- Presetting within a single calculation version of some hazardous substances and/or groups of substances with summing effect;
- Presetting of an “advisability” criterion to perform calculations;
- Presetting within a single calculation version of a number of areas or/and individual points to calculate concentrations;
- Calculation with 1 through 10 preset values of wind speed;
- Calculation with a step from 1 degree through 360 degrees in wind direction or using automatic mode of determining “dangerous” wind direction under which the concentration of hazardous substance reaches its maximum at the calculated point;
- Automatic selection of MAC value from maximum individual and average daily concentrations and from so-called “guiding safe impact level”;
- Calculation with consideration for background concentrations; and
- Calculation using a wind rose of 8- or 16-points to perform subsequent automatic correction of the buffer area.

The program complex does not use cartographic substrates and, thus, gives no way of performing direct dose calculations for both the personnel and the population.

Modeling System TRACE of Express- Forecast of Radiation Accident Consequences Developed at IBRAE RAN

The user is given the following possibilities [3.21]:

- Create thematic maps of different scale on the screen;
- Preset radioactive release parameters and perform calculations using the model of atmospheric transfer with mapping of the simulation results;
- Review and (if necessary) modify characteristics of the system elements, add new elements and describe their characteristics;
- Mapping the results of radiation monitoring sensor measurements;
- Analyze potential implications of releases in the form of text files (including report generation); and
- Maintain the current state of the system in a special configuration file to perform its reconstruction in the course of subsequent analysis.

According to its functional potentialities, the system is best suited to the branch regional IAC. Among the system shortcomings can be cited the application of a simple Gauss model of radioactive release dispersion in the atmosphere based on the 38.220.56-84 IPA «Interatomenergo» standard-technical document.

From the above analysis of the available models, one can suggest the following version of subdividing the potentialities to simulate spreading of radioactive releases between SEM of different levels.

At enterprise level, simulation is not advisable because of the involvement of rather sophisticated mathematical calculations and the need for participation of highly qualified experts. However, the enterprises should possess basic variants of potential accidents (calculated in advance) with consideration for enterprise specificity, in which the effects of buildings and orography on different wind directions would be taken into account. These variants should embrace all situations to rapidly estimate the release implications in a case where the hazardous contamination is confined within the enterprise site.

At a level of regional IAC, the installation of easy-in-use GIS-simulating complexes (of TRACE-type) to perform express estimations of the accident consequences is advisable. Such programs give no way of obtaining high-accuracy calculations; at the same time, they make it possible to obtain early estimations using a rather restricted amount of initial data. Moreover, these models allow for comparing the results of forecasts with real indices of monitoring sensors in automatic mode (this function is embedded into the TRACE-complex).

In a case where the release of contaminating substance (in hazardous quantities) exceeds the site bounds, regional IAC should inform federal centers (i.e., SCC, Roshydromet, etc.) and should draw upon their resources. Federal centers, in their turn, can invoke centers of technical support. At present it seems rather difficult to select and recommend software only from the above-considered program complexes, since every model has its particular merits and demerits. The choice of individual software complex (or of a combination of models) to simulate the consequences of a specific accident should be made under the competence of the authorized federal bodies. The task of regional IAC consists in presenting primary data for federal centers in the most comprehensive manner.

3.8. Proposals on the Order of Realizing the Concept of SEM within Territories Involved in Utilization of Radiation-Dangerous Installations of the Navy

From organizational standpoint, SEM creation and development should be based on the step-by-step principle. At the present stage of work, one can distinguish at least the following two stages.

First stage. Creation of the first SEM phase should use already-operating subsystems and services. Such substructures should to be unified into an integrated system on the basis of organizational, technical and informational compatibility and the sufficiency of the obtained information needed to perform functional tasks under both normal and off-normal operating conditions. Necessary components include: automated on-line control (first, over the radiation and chemical situation) and monitoring of the systems of radiation and chemical impact on environmental media and human health in areas of enterprises performing NS utilization.

Second stage. A full-scale SEM should be created, based on developing informational, functional and technical facilities to ensure multi-component ecological monitoring (including specific types of technogenic impact, such as: e.g., electromagnetic emission, biological pollution, etc.). At this stage, the SEM will allow for ensuring in full measure organizational, informational, scientific and methodic support for the following activities:

Control over the observance of ecological legislation at enterprises involved in NS utilization;

Maintaining enterprise inventory databases;

Use of environmental protection installations;

Protection and control over the health of personnel and of their families; and

Planning and realizing actions aimed at protecting the environment and the population under both normal and off-normal operating conditions at installations dealing with NS handling after the decommissioning.

The necessity of creating and developing SEM in keeping with the “step-by-step” principle results from several considerations. First, to resolve such a sophisticated problem, financial resources are lacking. Second, regional SEM is created as an element of primary control within the framework of USASCRS and USSEM, which, in their turn, are also created in two stages. Further reasons are the incompleteness of many actions related to the inventory of sources of radiation, chemical, etc. hazards at NS utilizing installations; to the ecological inventory of these installations; the substantiation of allowable values of releases to the atmosphere and effluents discharge into the water medium; etc.

The SEM realization time schedule should be specified at a stage of advance planning.

It is worth noting that one is dealing with the creation and the subsequent integration of the systems of ecological monitoring of NS utilizing installations into a higher-level system responsible for the ecological safety management in the whole region (such a system does not exist at the present time either). The task of complex assessment of the anthropogenic impact on the environment should have been resolved at the federal level via the creation of USSEM. But the problem appeared to be so laborious and required so many financial resources that it remains unresolved (even at the conceptual level). As was mentioned above, progress has been reached in the creation of USASCRS (a subsystem of USSEM). At present, an experimental USASCRS project attempts to unify the operation of existing specialized systems and departmental systems. There are problems of departmental separation, of different formats of data storage and presentation, of the lack of control over the many parameters needed to perform complex assessments, etc. However, in the present approach of creating specialized and departmental ecological centers (solving their local tasks) followed by their subsequent integration into larger structures and, finally, their unification at the federal level is preferable to attempting to develop a unified system in an “at once” manner. Real-life experience demonstrates that the task of creating a unified ecological monitoring system at the federal level still remains beyond our strength. But waiting for the development of common requirements for all ecological monitoring subsystems, the selection of contractors and assigning appropriate financing for their creation would result in postponement of many urgent tasks. Starting from the above conditions, we suggest the “step-by-step” mode of creating the ecological monitoring system for NS utilizing enterprises within the Northwest region of Russia (see below).

Developing requirements and creating local IAC at NS utilizing enterprises. Local IAC should generate and communicate to upper levels the data characterizing the ecological situation at the concerned enterprises. The information should be communicated using a common (for all enterprises) format to be developed from the viewpoint of its sufficiency for resolving ecological tasks. It is obvious that at present the extent of control at the concerned enterprises is not enough to solve ecological tasks in their entirety. The development of a format for presenting ecological data from enterprises will allow for revealing unsolved problems in the monitoring system and for purposeful equipping of NS utilizing enterprises with appropriate computer and methodological facilities. In addition to the format of data presentation, one needs to develop systems of information generation and communication, including facilities for automatic transmission. Due attention should be given to the “restricted access” status of some data.

Creation of regional and departmental IAC. The basic tasks to be solved by IAC are listed below:

Collecting information from enterprises involved in NS utilization process. To obtain such data in automatic mode, one needs to generate schedules of the corresponding data transmission and storage;

Maintaining a specialized database for NS utilizing enterprises;

Generating and communicating to the top departmental level (SCC, Minatom departments) and to the ecological center attached to regional authorities of the data related to the concerned enterprises. The departmental regional IAC should play a part of «filter»; on the one hand, to avoid communicating excessive primary information from enterprises to the top level and, on the other hand, to eliminate cases of communicating “restricted”-status data. Such an IAC would be able to overcome departmental contradictions arising when making efforts to integrate departmental information and perform complex assessment of the ecological situation;

Responding to accidents limited by BA and RCA of the concerned enterprises and, thus, not requiring regional-level intervention. For these purposes departmental IAC should be equipped with rather simple but reliable and effective facilities for predicting the consequences of local radiation accidents. To obtain primary data, which are required to realize the above forecasts, interactions with Roshydromet departments should be provided; and

In a case of initiating major radiation accidents, departmental regional IAC should be a source of comprehensive information for analytical centers and technical support centers of the top level.

<u>Creation of ASCRS for BA of Enterprises Involved in NS Utilization.</u> The systems are principally aimed at informing the population and regional authorities on the real radiation impact of the concerned enterprises on the environment. Such systems should be operated using the enterprise resources. At present, a project at Murmansk Territorial ASCRS (created by the joint efforts of the Regional Department of Hydrometeoroloical Service and Murmansk Regional Authorities) is being operated with success. However, in keeping with their status, Roshydromet structures are not allowed to control the buffer area of enterprises, which in most cases have CATS-status. At the first stage, it is advisable to connect newly created specialized ASCRS to MT ASCRS. In the future, the data of specialized ASCRS will be communicated simultaneously to IAC attached to regional authorities and to regional departmental IAC.

<u>Creation of an Ecological Center Attached to the Authorities of Northwest Region</u>. In keeping with its status, the ecological center attached to regional authorities is the only structure that is able to accumulate information from many departments authorized to ensure the ecological safety of the region. However, no criterion of assessing the ecological situation based on the generalization of the data coming from different departmental structures is available at this time. At the first stage, to collect and store information of different departments, a special format should be developed aimed at solving some generalized tasks dealing with the ecological safety estimations (see Chapter 3.3.). The center attached to the Northwest regional authorities should be a source of "ecological" information for the population, different public organizations and top-level structures. Functions of regional ecological IAC will be worked out in detail only following the creation of the USSEM structure. But such a task is beyond the power of the authors of the present report.

The structure depicted in Figure 3.3 can be developed further, however. In the author's opinion, the approval of the already-suggested stages (at least) should be performed first.

The concept realization will make it possible to:

> Ensure the creation of an automated system of ecological monitoring in areas of NS utilizing enterprise locations, which will be able to control routinely levels of the environmental media contamination and to estimate the technogenic impact on both the environment and human health; and
>
> Provide information-analytical support of the making-decision process when carrying out environmental protection actions at enterprises involved in NS utilization. This will result in upgrading of reliability, efficiency, trustworthiness and validity of decisions to be made and their effectiveness. The creation of SEM will contribute to the generation of a unified system of ecological monitoring over NS utilizing enterprises, as well as of USASCRS and USSEM systems.

From a social standpoint, the creation of SEM at the concerned enterprises will constitute a part of actions aimed at ensuring constitutional rights for safety of RF citizens. It will also assist the State in the adequate solution of ecological, sanitary and epidemiological issues for the sake of the population in Russia and the neighboring countries.

3.9. Approximate List of Software & Hardware Necessary to Realize the First Stage of the System of Ecological Monitoring within Territories & Water Areas of Operating and Utilizing Radiation-Dangerous Units and Installations of the Navy

As mentioned above, joining up already-existing systems and services and minimum development of new ones (needed to ensure the current level of ecological safety only) are recommended as the first stage of SEM creation. Thus, listed below are proposals on software and hardware needed to create the following SEM elements:

- radioecological monitoring system and IAC at enterprises;
- local ASCRS for settlements situated close to utilization facilities; and
- departmental regional IAC.

In most cases the existing systems can be only used to solve tasks of radioecological monitoring. Issues of control over concentrations of hazardous chemical substances in the environmental media necessitate special devices, which at present are unavailable at enterprises. The task of complex standardization of chemical pollutant concentrations in the environmental media is unsolved also. In the author’s opinion, it is only the *radio*ecological monitoring system (SREM) that is realizable in the course of a relatively short period of time. The development of a full-scale system of ecological monitoring will necessitate both time and finances that are, *a priori*, beyond the resources of the ATRP-R Project. In the author’s opinion, the first-priority task of now is, at least, ensuring the current level of radiation safety at the units and installations under consideration. Unfortunately, at present even this task is not always solved satisfactorily.

3.9.1. Software and Hardware of SREM at Enterprise Level

During the first stage of SREM concept realization at enterprise level, equipping enterprises with a set of automatically operating sensors is suggested. The author’s experience on the development of such systems demonstrates the following. To solve tasks of radioecological monitoring at the enterprise level (without consideration for issues of technological control), one needs: -about 10 gamma dose rate sensors; - two submersible spectral sensors for control over the radioactivity in water medium; and - two mobile devices measuring concentrations of radioactive aerosols. The approximate cost of such a set of equipment made by Russian manufactures is about 50,000 USD.

The sensors are controlled and transfer information to computers using special devices, so called «Intellectual Controllers» (IC), which ensure an appropriate interface. The communication between dose rate sensors, submersible sensors, intellectual controllers and computers is realized via cable lines. To transfer indices of mobile sensors (which detect radioactive aerosols) to computers, the use of radio-modems is recommended. The available IC of Russian design make it possible to connect up to four sensors to one IC and several IC to one computer. However, with consideration for the needed arrangement of sensors over the territory of enterprises under consideration and the number of information consumers, one needs about six IC (the approximate cost of 20,000 USD) and four computers to ensure operation of the above-indicated set of sensors.

The mean cost of computers (including the cost of both the needed integration and peripherals) makes up about 14,000 USD. The cost of general-system license software (MS Windows 2000, MS Office, etc.) needed to fit one computer makes up about 500 USD (2,000 USD for four computers). To this, the cost of network software, database management system and software tools for the whole set (MS SQL Server, MS Windows 2000 Server), about 5,000 USD should be added.

Within every concerned enterprise, computers should be integrated into a Local Network (LN). The cost of creating such a network at the enterprise territory (cables, cable laying, network concentrators (Hubs), mounting, etc.) depends considerably on its individual configuration and, therefore, varies from 20,000 to 50,000 USD.

The cost of application software allowing for automating of measurements, processing, visualization and transmission of data, information protection, etc. is estimated at about 30,000 USD.

The cost of telecommunication lines between the concerned enterprises and departmental IAC is most uncertain. Here, two principal solutions are possible:

- 1) laying of a separate cable line (maybe a fiber-optic cable line) between the enterprise and IAC; or
- 2) renting an available telephone line.
  As a reserve, a switched telephone channel should be used (dial-up operation mode).

The first alternative represents the optimum solution; however, it is not always realizable due to the remoteness of many concerned units and installations from large settlements (especially in Extreme North regions). The ability to protect information depends on the degree of its secrecy. Thus, in every individual case the relevant authorities should coordinate these issues. The requirements for computer-gateways or firewalls transmitting information from LN to an upper level as well as to their software should be generated depending on specific requirements of the above authorities. The possibility of applying cryptographic facilities for the information protection should be also considered. It is worth noting that this issue should be solved individually depending on the enterprise location, secrecy of work to be carried out and actual potentialities.

Mobile subsystems represent a necessary component of the monitoring system. Taking into account that the distance between some stationary posts can reach several kilometers, in a case of radiation accident stationary sensors will be able to record only the fact of such an accident. To carry out quantitative interpretation of the data on the release amount and to determine a set of appropriate countermeasures, a more detailed survey (over a grid: one monitoring post every few tens of meters) is necessary. However, installing and equipping stationary posts at such a frequency is inexpedient.

Among the principal parameters of the radiation situation to be measured on-line or estimated using mobile radiation monitoring devices, the following characteristics should be cited:

- gamma dose rate;
- isotopic composition of principal dose-generating nuclides;
- surface alpha- or beta- contamination; and
- radionuclide concentration in the air.

In addition, when performing on-line monitoring, one needs a navigation system with a rather high spatial resolution to refer the measured values to local coordinates.

The approximate cost of a mobile radiometric laboratory made by Russian producers including a car, measuring devices, computing facilities, data transmission facilities and auxiliary equipment makes up about 35,000 USD. The total estimated cost for equipping enterprises with SREM software and hardware is about 200,000 USD (without labor costs for installation).

3.9.2. ASCRS for Settlements Located in the Vicinity of Enterprises Dealing with Utilization

In real-life conditions, ASCRS-systems in settlements are mainly aimed at informing both the concerned population and the local authorities on the “normal” state of radiation. In a case of initiating emergency, much more data and many qualified specialists (as compared to those available in a non-specialized organization) are required to analyze the off-normal situation and elaborate appropriate decisions. Therefore, the installation and equipment of some stationary posts of gamma dose rate measurements (three to four at the most) in the vicinity of such settlements along the azimuths of the nearest radiation-dangerous units and installations is advisable. Taking into account the requirements for minimum servicing of the posts under consideration, data communication from such posts should be organized via radio channels. The radius of action of the system should allow for data communication-reception within the limits of both the buffer area and the radiation-control area of the concerned enterprises (several tens of kilometers).

This information will be consumed by:

- local authorities of the concerned settlements (in their office the installation of an information (indicator) panel will be sufficient), and
- IAC of enterprises wherein the indices of ASCRS sensors will be integrated into a unified system and, next, communicated to an upper level (departmental regional IAC).

At present some systems developed in keeping with all the above-listed requirements are already available. By way of example, both ASCRS «Atlant-R»-system made in Russia [3.22.] and "SkyLINK"-system produced in Germany [3.23.] operating at Russian and foreign NPP can be cited. These systems consist of radio-transmitting control posts and a central post for information collection and processing. The cost of the Russian post of measurements makes up 4,500-5,000 USD, of the foreign-one (of "SkyLINK"-type) about 16,000 USD. The cost of central posts made by Russian and foreign manufacturers makes up 12,000 USD and 30,000 USD, respectively.

Thus, the cost of ASCRS for a settlement varies from 30,000 to 100,000 USD depending on the choice of the system manufacturer. It is worth noting that servicing of such systems should be entrusted to enterprises possessing the appropriate financial and personnel resources.

3.9.3. Equipment of Regional Departmental IAC

Basic tasks and functions of regional departmental IAC were listed in Chapter 3.6.3., whereas the requirements for dataware were considered in Chapter 3.7.2. Both the structure of departmental IAC and their equipment for utilization enterprises necessitate further development and working out in detail. Note that in the Northwest region of Russia the creation of, at least, two IAC is advisable: a IAC under «SevRAO» in Murmansk-town (attached to Minatom of Russia) and a IAC in Severodvinsk-town under Rossudostroenie (attached to Ministry of Economy). Individual requirements for every center and its structure can be slightly different depending on the higher-level organization.

At present, the following elements are needed to ensure successful operation of departmental IAC:

- «a base of knowledge» for utilization enterprises (see Figure 3.4). Some elements of this database are already available; some others necessitate further development. The approximate cost of target generation of such a «base of knowledge» for departmental regional IAC (the first stage) makes up at least 40,000 USD;
- a database on the radiation situation at enterprises performing utilization. The development of such a database will require the creation of a structure, schedules and formats of data exchange with enterprise IAC, formats of data storage and presentation, schedule of data communication and exchange with an upper-level center (SCC of Minatom), generation of a system of data visualization and presentation. The approximate cost of such a system (including the cost of standard software for DBMS and GIS) makes up at least 40,000 USD;
- local network (including computers, auxiliary equipment and standard software) which cost is estimated at about 40, 000 USD;
- software to simulate and forecast the radiation situation in a case of accident. The already available software was described in Chapter 3.7.4, however, when installing any of these devices, additional programming will be necessary (for generation of necessary electronic maps, introducing parameters of possible release sources of potential accidents at units and installations under consideration, etc.). The approximate cost of the enhanced modeling software to be installed in a regional departmental IAC makes up at least 25,000 USD;
- protected lines and protocols of communication with enterprises, regional authorities and SCC of Minatom. In author's opinion, at present this issue is the most complicated and needs further working out. It is obvious that communication lines with enterprises (as with the transmitters of initial, in many cases classified, information) should be the most reliable and best protected (see Chapter 3.9.1.). Local authorities receive non-secret ("open") information on the radiation situation in settlements and their neighborhood (however, appropriate devices for its protection against distortion should be provided as well). To inform the general population, the creation of a specialized site on the Internet is advisable. Here everyone will be able to obtain "open"-status data related to the problem under consideration. As it was mentioned above, the issues of in-departmental communication, requiring extra reliability and protectability, are most complex. The actual practice at Minatom enterprises demonstrates that under normal operating conditions data transmission via the Internet once a day in the form of a special "electronic letter" containing a set of data (as a sequential collection of numbers in a special format preset in advance) is sufficient. However, in a case of emergency, both the data volume and transfer rate as well as the requirements of the degree of protection and reliability of the transmitted data increase many times. Thus, for cases of emergency the creation of a special "emergency" communication line is necessary, e.g., of a satellite channel with cryptographic protection (these issues, however, being in the competence of SCC of Minatom, remain beyond the tasks of the given Project).

The approximate cost of both the software and hardware to equip departmental regional IAC of the first stage is estimated at about 150,000 to 200,000 USD.

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4. Review of Standard & Legal Documentation Related to the Problems of Ensuring Safety during the Process of Nuclear Submarine Utilization

4.1 General Characteristics of International Legal Regulating Documents to Ensure the Ecological Safety when NS Decommissioning and Handling of SF & RW

To realize standard and legal regulation and to ensure safety when handling NS, SF and RW, multi-step documentation is available of both “direct” and “framework” action. As a rule, the “top-level” documentation is of framework action. The documentation of lower levels (see Figure 4-1) falls into the category of “direct action” documents; these acts are to correspond to the requirements of the “framework” standard and legal documentation.

The issues related to NS utilization, management of SF and RW created when NS handling, environmental protection, and ensuring the ecological safety constitute the subject of both multilateral and bilateral cooperation between Russia and foreign countries.

Safe NS utilization and handling of RW and SF (the latter being considered as highly enriched uranium at the instant of burnup) form an integral part of a more general global problem of preventing the proliferation of weapons of mass destruction (i.e., non-proliferation of nuclear weapons). Therefore, among general-purpose international legal documents, which play an important part in regulating issues of environmental protection against radioactive contamination and in ensuring the ecological safety, the following two documents should be mentioned first:

Treaty of the Non-Proliferation of Nuclear Weapons (Non-Proliferation Treaty) of 1968, ratified by the USSR in 1970 [4.1] and

Treaty on the Prohibition of the Emplacement of Nuclear Weapons and Other Weapons of Mass Destruction on the Sea-Bed and the Ocean Floor and in the Subsoil Thereof (Sea-Bed Treaty) of 1971, ratified in 1972 [4.2].

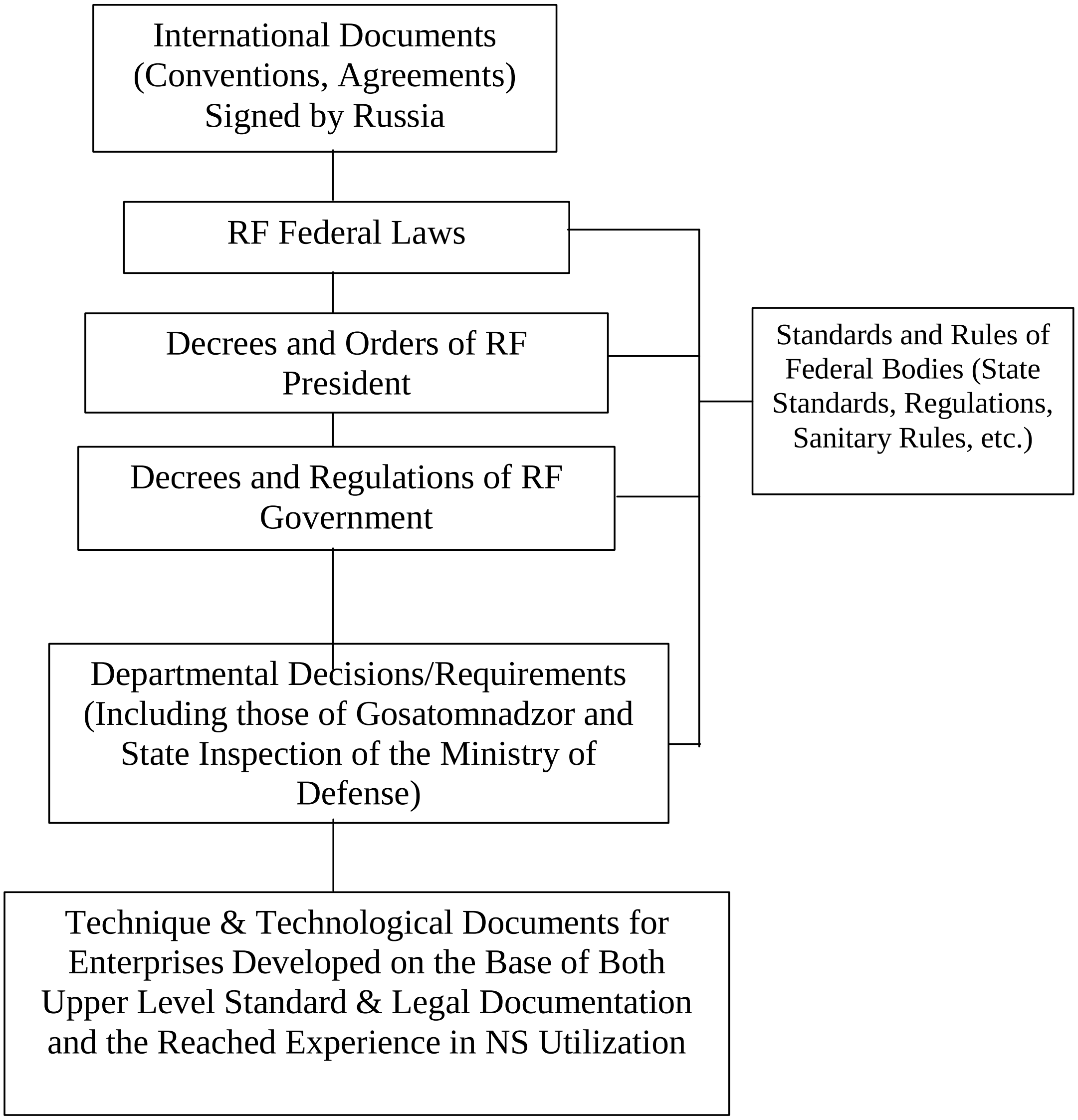

Figure 4.1. Structure of Standard and Legal Documentation Regulating Safety Issues during the Process of NS Utilization and SF & RW Handling

Within the framework of the sea law, the following two fundamental international documents should be mentioned above all among multilateral international conventions related to the subject under consideration:

1958 Geneva Convention on the High Seas [4.3] that obliges the involved countries «to take measures in order to prevent the marine environment contamination against radioactive wastes dumping with consideration for all standard and legal documents, which can be developed by competent international organizations» (Chapter 1, Article

25). The Convention was ratified by the USSR on the 20th of October 1960 and came into force on the 30th of September 1962; and

1982 UN Convention on the Law of the Sea [4.4] representing an important step to prevent World Ocean pollution and contamination. The Convention includes many important clauses related to the prevention of Sea contamination by radioactive wastes. The document came into force on the 16th of November 1994 and was ratified by Federal Law of the Russian Federation of January 22, 1997).

The London Convention of 1972 on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter [4.5] regulates the issues directly related to the dumping of radioactive wastes into the marine environment. The document was ratified by the USSR on the 15th of December 1975 and came into effect on the 29th of January 1976. The Convention terms are applied to all types of vessels including nuclear submarines. According to the Convention, every deliberate marine disposal of wastes or other materials from vessels as well as deliberate destruction of vessels themselves is to be considered as "waste dumping". Furthermore, the dumping of wastes or other materials transported by vessels for purposes of removing such materials as well as the dumping of substances resulting from the treatment of wastes or other materials on such vessels is also ruled by the Convention. The pollutants, whose dumping is regulated by the Convention of 1972, are subdivided into three categories. «Radioactive wastes of high radiation level or other radioactive wastes whose levels are considered by the IAEA as inadmissible for marine disposal because of biological, health protection and other reasons» are qualified as substances of which dumping is strictly prohibited (Annex № I of the Convention). The Annex № II deals with substances and materials whose disposal into the marine environment is not prohibited absolutely because of less potential hazard. At the same time, competent authorities control their dumping in a strict manner - every time prior to dumping one needs a special authorization. Among different substances, this group comprises all radioactive wastes that remain outside of Annex I.

In 1993, a correction to the London Convention of 1972 on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter was approved, which prohibits marine disposal of radioactive and other materials. Though Russia has not joined the correction yet, the RF Government «will press towards joining the correction, as soon as possible, for purposes of protecting the environment in seas surrounding Russia, including the Japan Sea. Prior to acceding to the correction, Russia will forbear from radioactive waste dumping into the marine environment». (See the Regulation № 1271 – r of RF Government of September 8, 2000 «On the Project of Memorandum on the Development of Cooperation between the Government of Russia and the Government of Japan in the Field of Promotion of Disarmament, Non-Proliferation and Utilization of Nuclear Weapons to be Decommissioned in the Russian Federation») [4.6].

In regard to the present review, the Convention on Environmental Impact Assessment in a Transboundary Context of 1991 [4.7], signed on the 6th of July 1991 and ratified by Russia on the 22nd of January 1997 is another important international document. In keeping with the Convention, the involved countries are to take steps in order to prevent and/or decrease hazardous transboundary impact resulting from planned actions and create a system of diminishing and monitoring transboundary effects. Such measures include an estimate of the potential transboundary impact on the environment prior to making a decision on realizing a planned action and the notification of the concerned parties of the action to be carried out. The list of actions (see Appendix № 1 of the Convention) includes the activities related to installations of nuclear fuel production or enrichment, SF regeneration or collection and RW removal and treatment.

From the viewpoint of the presented review, the "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management of 1977" [4.8] is one of most important documents. The Convention was signed by Russia in 1998 (see RF Government Regulation of November 25, 1998, RF President Decree of December 28, 1998). In keeping with the Article 15 of the Federal Law «On International Agreements of the Russian Federation» of July 15, 1995 [4.9], the Convention does not require obligatory ratification despite the well-known opposite point of view. The Convention field of application covers issues of handling of SF and RW being created in the process of commercial power facility operation. As indicated in Article 3.3 of the document, «the Convention cannot be applied to safe handling of SF or RW within the framework of military or defense programs excepting cases that they are declared as "spent fuel" or "radioactive wastes" by a Contracting party for special purposes of the given Convention". At the same time "…the Convention is applied to ensure safe handling of SF within the framework of military or defense programs, if such materials are ultimately transferred to non-defense programs and if their handling is carried out within the framework of civil programs only». Thus, in keeping with the RF Government, in some cases the issues of safe handling of SF and RW when decommissioning of both NS and military-purpose surface vessels with PRF are regulated by the Joint Convention.

Regional international standards related to environmental protection against radioactive contamination, as well as multilateral international projects in the field under consideration (e.g., CTR, AMEC, TACIS) are also of much importance.

Among regional standard and legal documents, The Convention on the Protection of the Marine Environment of the Baltic Sea Area of 1992 [4.10] (approved by the Regulation № 1202 of RF Government of October 15, 1998) should be emphasized. According to Article 4.3 of the Convention, the document is not applied to the military area (nuclear submarines). But at the same time, it is also stated that "every contracting party ensures, as far as possible, the operation of military vessels in keeping with the Convention clauses via the application of appropriate measures". This concerns, in particular, the application of provisions of Annex IV «Marine Disposal from Vessels».

The "Program of the Barents Euro-Arctic Council on the Environment Protection" of 15.06.1994 [4.11] should be cited among documents that regulate the international cooperation in the area of both environmental protection and the prevention of radioactive contamination resulting from both civil and military activities in the North of Europe. First of all, the Program concerns the Barents Sea region.

Bilateral International Cooperation

The bilateral Russian-Norwegian cooperation aimed at preventing radioactive contamination of the North region by RW and SF created in the process of both nuclear disarmament and utilization of the decommissioned nuclear submarines in Russia is regulated in a most detailed way. Among the principal legal acts related to the environmental protection and nuclear and radiation safety within the framework of the Russian-Norwegian cooperation, the following documents should be cited:

Agreement between the Government of the Russian Federation and the Government of Norway on the Cooperation in the Field of Environment Protection of September 3, 1992 [4.12];

Agreement between the Ministry of Defense of the Russian Federation and the Ministry of Defense of Norway on the Cooperation in the Military Area Related to the Environment Protection of December 15, 1995 [4.13];

Memorandum on the Cooperation between Russia and Norway in the Field of Nuclear Safety of October 4, 1995 [4.14];

Declarations on Basic Principles of Relations between the Russian Federation and Norway of March 26, 1996 [4.15]; and

Agreement between the Government of the Russian Federation and the Government of Norway on the Cooperation in the Field of Environment Protection Related to Utilization of the Decommissioned Russian Nuclear Submarines in the North Region and Improving Nuclear & Radiation Safety of May 26, 1998 [4.16]. The Agreement Project was approved by the Regulation № 1448 of RF Government of November 18, 1997; additions and modifications were introduced into the Agreement by the Decree № 1006 of RF President of September 4, 1999.

In keeping with the above documents, the Norwegian Party renders the Russian Party non-repayable technical and financial assistance aimed at ensuring safe and economically justified utilization of the decommissioned nuclear submarines of the Russian Navy in the North region and handling of SF and RW created during this process. Within the framework of the bilateral cooperation the following projects are carried out:

- development of methods of SF management when utilizing NS;
- creation (designing, building and putting into operation) of SF, SRW and LRW repositories, as well as of facilities to transport SF, SRW and LRW;
- modernization of the existing repository of LRW interim storage and the delivery of installations to perform LRW treatment; and
- utilization of individual nuclear units and installations (floating servicing enterprise), etc.

In 1999, the Agreement was supplemented with new projects dealing with SF and RW management. The most important projects are listed below:

- developing and making a prototype model of a transportation cask to store SF of nuclear submarines temporarily;
- designing, constructing and putting into operation a model site to store SF temporarily;
- designing and creating a mobile multi-purpose module-type complex to reprocess LRW created when NS handling after decommissioning; and

- designing and creating a complex of installations to reprocess SRW created and accumulated as a result of NS utilization.

The Netherlands is the second in importance international partner of Russia in the field of safe utilization of decommissioned NS of the Russian Navy in the North region. In 1999, an Agreement was signed between the Government of the Russian Federation and the Government of the Netherlands. The agreement is known under the name “On Safe Destruction of Nuclear Weapons Reduced in the Russian Federation and on Safe Utilization of Russian Nuclear Submarines Decommissioned from the Navy in the North Region” (see Regulation № 275 of RF Government of March 11, 1999) [4.17].

In keeping with the agreement, non-repayable financial assistance will be rendered to Russia for purposes of:

- safe and effective storage of fissile materials created in the process of destroying nuclear weapons to be reduced in the Russian Federation within the framework of international agreements or one-sidedly; and
- rapid and environmentally safe NS utilization including the handling of SF and RW created in this process.

The considered international Agreements are realized in the form of so-called «Project Agreements». By this is meant that individual agreements are concluded between Russian organizations and the Netherlands project executors appointed by competent bodies of the two Parties. The Project Agreements come into force only following their approval by the above-mentioned bodies. A list of individual projects forming the subject of bilateral cooperation (e.g., making of containers for SF transportation or SF long-term storage) is given in the Agreement Annex.

With the aim of rendering assistance in the field of safe nuclear weapons destruction in Russia, the following two international agreements were concluded between the Russian Federation and France:

> «The Agreement between the Government of the Russian Federation and the Government of France on the Cooperation in the Field of Safe Destruction of Nuclear Weapons in Russia and the Use of Nuclear Materials Created in that Way for Peaceful Purposes» [4.18] and

> «The Agreement on the Cooperation in the Field of Safety and Monitoring of the Radiation Situation in the Course of Transportation, Storage and Destruction of Nuclear Weapons in Russia» [4.19].

Both Agreements were concluded on the 12th of November 1992 and came into force on the 30th of March 1993. However, these agreements are dealing with general issues of the cooperation related to safe destruction of nuclear weapons in Russia; the problems of ensuring safety when utilizing NS are not separated into an individual subject of regulation.

The Russian-Japanese cooperation in the field of assisting disarmament and nuclear weapons utilization, including NS to be decommissioned by Russia in the Pacific, is progressing rapidly. As was stressed more than once in a number of bilateral documents, the utilization of NS is a top-priority problem from the viewpoint of control over armaments and disarmament and environmental protection within the Japan Sea area. From the standpoint of safety, such activities are rather important not only for Russia but also for the entire Asiatic-Pacific region.

On the 13th of November 1993, an agreement was concluded between the Government of Russia and the Government of Japan. The agreement is known by the name of "On the Cooperation in the Field of Promoting Destruction of Nuclear Weapons to Be Decommissioned in Russia and on the Creation of a Committee on the Cooperation Dealing with these Issues" [4.20]. The Agreement constitutes the legal basis of the bilateral cooperation between Russia and Japan. In keeping with the Agreement and for purposes of rendering Russia assistance in solving problems of the destruction of nuclear weapons to be decommissioned in Russia and of the related problems of environmental protection, a special intergovernmental body was created. This structure is known as "The Committee on Cooperation for Purposes of Rendering Assistance in the Area of Destroying Reducible Nuclear Weapons ". The Agreement identifies the tasks which face the Committee.

To realize the tasks of the Agreement, an International contract was concluded on the 11th of January 1996 within the Agreement framework to create, at Japan's expense, a floating complex "Landysh" in Primorskiy kraj on treatment of LRW produced when NS decommissioning. The procedures of acceptance and ensuing operation of the created floating complex were regulated in a special Regulation № 1633 of RF Government of November 27, 1997 « On Floating Complex of Liquid Radioactive Wastes Treatment» [4.21]. It is especially stressed in the Regulation that the complex is an installation to be used exclusively for purposes of environmental protection.

In the Moscow Declaration of November 13, 1998 [4.22] (dealing with Russian-Japan relations in the field under consideration), the parties stressed the importance of bilateral relations, as applied to the issues of nuclear weapons dismantling and resulting problems of storage, control and processing of nuclear materials. The declaration is known under the name of «On Constructive Partnership between the Russian Federation and Japan». To realize the above arrangements with consideration for the concern of neighboring countries, a decision was made to create a joint Russian-Japan Group dealing with issues of marine disposal of radioactive wastes.

Russian-Japan contacts in the area of promoting nuclear disarmament in Russia and ensuring ecological safety within the Asian-Pacific region were continued in the following document:

> "The Memorandum on the Development of Collaboration between the Government of the Russian Federation and the Government of Japan in the Field of Promoting Disarmament, Non-Proliferation and Utilization of Reducible Nuclear Weapons in the Russian Federation". The project of "Memorandum" was approved by the Decree № 1271-r of RF Government of September 8, 2000 [4.23].

Moreover, the considered document confirms the intention of the Japan Party to render Russia financial support in solving problems of NS utilization within Far East region, in keeping with the resolution of the Board of Committee of July 26, 1999. In particular, this concerns the realization of the following new projects:

- SF unloading out of multipurpose NS in waterborne storage, SF loading into transportation casks, construction of a site to store SF;
- NS utilization at «Zvezda» shipyard; and
- "Pinega"-tanker reconstruction into a container ship to transport TC with SF (unloaded from NS) up to the area of SF loading into special trains.

Future development of another joint project in the area under consideration is provided.

The realization of the projects outlined in the Memorandum and other Russian-Japan agreements should contribute to ensuring environmental safety in the Japan Sea area.

The issues of nuclear disarmament and ensuring safety in the context of the activities in question constitute a subject of collaboration between Russia and the USA. The Regulation № 744 of RF Government of June 24, 1996 referred to as «On the Order of Realizing International Agreements in the Field of Safety when Storing and Transporting Nuclear Weapons in RF in the Context of Its Reduction» [4.24] approved:

"The Agreement between the Ministry of Defense of Russia and the Ministry of Defense of the United States on the Collaboration in the Field of Safe Storage of Nuclear Weapons through Provision of Material and Technical Facilities, Rendering Services and of Appropriate Education" of April 3, 1995 and

"The Agreement between the Ministry of Defense of Russia and the Ministry of Defense of the United States on the Collaboration in the Field of Safety when Transporting Nuclear Weapons through Provision of Material and Technical Facilities, Rendering Services and of Appropriate Education" of April 3, 1995 [4.25].

The whole activities within the framework of the above agreements are under effect of "The Agreement between the Russian Federation and the United States of America Related to Safe and Secure Transportation, Storage and Destruction of Weapons and to the Prevention of Weapons Proliferation" of June 17, 1992. It is worthy of notice that on the 17th of July 1999, the Agreement term was prolonged for an additional seven years [4.26].

The above analysis allows for concluding that both multilateral and bilateral cooperation is progressing rapidly in the area under consideration. At the same time, not all important issues of NS utilization and related problems for Russia constitute the subject of international cooperation. E.g., at present the utilization of multi-purpose NS is one of most pressing issues of NS handling after the decommissioning in Russia; however, this subject is not included into international disarmament programs. Also pressing are the problems of developing an international action plan and of creating an international fund dealing with issues of handling of SF and RW created in the process of NS utilization, et al. Among other related problems, the above issues can constitute the subject matter of a new multilateral international agreement in the area of ensuring the ecological safety and carrying out environmental monitoring during the process of NS utilization and handling of SF and RW.

4.2. Review of Russian Legal-Regulatory Documentation Related to the Issues of NS Utilization after the Decommissioning and Handling of SF & RW Resulting from These Operations

4.2.1. General Issues of NS Utilization and SF & RW Handling

In keeping with the Concept of National Safety approved by the Decree № 1300 of RF President of December 17, 1997 (№ 24 in edition of January 10, 2000) [4.27], the problems related to NS utilization are considered a top-priority task among the environmental protection activities of the Russian Federation.

According to the Decree № 1300 of the RF Government of September 30, 2000 «On Approving Regulations Dealing with the Use of Finances Coming in the Federal Budget Revenue as the Result of Selling Products of Armaments and Materiel Utilization» [4.28], by the utilization of armaments and materiel (including NS utilization, as a component part) is meant the following. This is a system of necessary organizational, technical and other actions, which ensure demilitarization, diversification of samples of armaments and materiel (including those to be reduced in keeping with international agreements) and obtaining the utilization products for their subsequent use in the national economy.

The above document regulates general issues of organizing activities related to armament and materiel utilization.

NS utilization operations are closely connected with the work related to handling of both SF (unloading, storage, transportation and reprocessing) created in the process of NS utilization and RW (storage and treatment) generated during NS operation.

As applied to the issues of NS utilization, the target of the State policy consists of: - ensuring safety when RW & SF handling, - realizing measures on protection of the population against radioactive contamination and - rehabilitation of the contaminated territories [4.29].

An analysis of the Russian legislation demonstrates that legislative documents as well as other standard acts regulate only individual issues of NS utilization and resulting problems of SF handling and RW disposal. But no concept is developed to determine basic goals and tasks of such work.

There is no unified act allowing for treating SF or RW as a subject matter of an independent regulation.

E.g., the Federal Law «On the Use of Atomic Energy» [4.29] is a general-purpose document, which determines basic principles of regulating the use of atomic energy for both peaceful and defense purposes. The activities related to the development, making, testing, use and utilization of nuclear weapons and power reactor facilities for military purposes are out of the Law. These activities are to be regulated by other Federal Laws, in particular, by FL «On Creation, Use, Destruction and Ensuring Safety of Nuclear Weapons» [4.30], which has been already approved by the Federal Assembly but is not signed yet by the RF President and, thus, is not put in force. The development of other legislative documents is also provided within the framework of the area under examination.

In addition to special legal regulation, the activities related to NS utilization and handling of SF and RW (resulting from this process) are to be carried out in keeping with the general requirements of the Federal Ecological Legislation. In particular, the following legal documents are worthy of consideration: the laws «On the Environment Protection» [4.31] and «On the Ecological Appraisal» [4.32] as well as the federal law «On the Radiation Safety of the Population» [4.33] and the federal law «On Sanitary and Epidemiological Welfare of the Population” [4.34].

The activities in question are licensed in keeping with the following two documents:

- “The Regulations on Licensing the Activities related to the Development, Fabrication and Utilization of Armaments, Materiel and Ammunition” approved by Regulation № 358 of RF Government of March 27, 1998 [4.35] and
- the Order of the RF Ministry of National Economy № 323 of August 14, 1998 «On Approving the Order of Actions Related to Licensing of Activities related to the Development, Fabrication and Utilization of Armaments, Materiel and Ammunition» [4.36].

The above documents determine the order of licensing of the activities of juridical persons related to the utilization of armaments, materiel and ammunition, their accessories and component parts regardless of the form of ownership. The exceptions are nuclear ammunition and power facilities for military purposes and the concerned activities of federal executive institutions, which have troops and armed units under their jurisdiction.

At the present time, the surveillance over safety of nuclear power facilities transferred to utilization rests on both the Gosatomnadzor of Russia and the Ministry of Defense of Russia. Their functions are separated as follows. In keeping with the "Statute of Gosatomnadzor of Russia" (approved by the Decree № 283-rp of the RF President of June 5, 1992 [4.37]), Gosatomnadzor exerts surveillance over the safety of vessel PRF transferred to industrial enterprises for utilization as well as over observance of the radiation safety rules and standards. In keeping with the "Statute of Ministry of Defense of the Russian Federation", the Ministry of Defense of Russia is entrusted with the surveillance over nuclear and radiation safety when developing, making, testing, operating, storing and utilizing nuclear weapons and nuclear power facilities for military purposes. The document was approved by the Decree № 1357 of the RF President of November 11, 1998 [4.38].

4.2.2. Spent Fuel Management

According to the Russian Federation legislation, spent fuel (SF) is not considered as an individual category of radioactive materials. At the same time, the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [4.8] distinguishes definitively the notions of "Radioactive Wastes" and "Spent Fuel".

In keeping with the Convention, by SF is meant nuclear fuel irradiated in a reactor core and unloaded ultimately from the core. SF is to be considered not only as a future source of energy but also as a raw material to produce heat-generating isotopes and noble metals in order to use them in technological catalysts and some other useful materials.

In “Rules of Physical Protection of Nuclear Materials, Power Installations and Units of Storing Nuclear Materials” approved by the Regulation № 264 of RF Government of March 7, 1997 [4.39], spent nuclear fuel is defined as “irradiated fuel not to be used in reactors in the future”.

It is worthy of notice that, at present, only individual issues of SF handling are regulated by legal acts in force.

According to Article 47 of the Federal Law «On the Use of Atomic Energy», SF reprocessing for purposes of extracting valuable components is to be performed in keeping with the Russian Federation legislation. However, no legislative document in the field of SF management is approved yet.

4.2.3. Radioactive Waste Management

According to the definition of the federal law «On the Use of Atomic Energy», Radioactive Wastes (RW) are “…substances emitting ionizing radiation but not to be considered as nuclear materials”.

In keeping with the Joint Convention [4.8], by RW are meant gaseous, liquid or solid radioactive materials not to be used in the future.

The basic lines of the RF public policy in the field of handling of nuclear materials, radioactive substances and RW consist in ensuring nuclear and radiation safety, preventing accidents with radiological implications and, if occurred, mitigating their consequences.

In keeping with the federal law «On the Use of Atomic Energy», all RW comes under federal ownership without any exception. The above law provides for creating and operating a state system of RS and RW registration and control and determines requirements for rules of nuclear material and RW transportation. According to the law, actions aimed at preventing transport incidents and accidents as well as at protecting personnel concerned with the use of atomic energy, the population, the environment and material values are obligatory. The law also determines basic requirements to RW storage, treatment and disposal.

Storage of RW is considered as a preparing stage to their treatment or disposal.

Other federal laws also regulate issues of RW handling. Among them the most important documents are the Federal Law «On the Subsurface» and the RFSSR Law «On the Environment Protection».

The RF Law «On the Subsurface» №2395-1 of February 21, 1992 [4.40] determines basic rules and principles related to geological investigations and the extraction of individual types of mineral resources as well as to the disposal of RW and toxic wastes. Other federal laws dealing with the subject under consideration are to take into account the provisions of the above law. The Law «On the Subsurface» also determines the circle of subsurface users when extracting radioactive materials and disposing toxic wastes or other hazardous wastes. Such activities are allowed only to juridical persons registered within the RF territory and possessing permissions (licenses) granted by an executive federal institution authorized in the extraction and use of radioactive materials, and disposal of toxic and other hazardous wastes. To obtain a license for the use of an individual subsurface section for purposes of storing radioactive, toxic and other hazardous wastes in deep structures (providing for their localization), one needs a special resolution of the RF Government coordinated with executive authorities of the RF subjects. In keeping with the RF legislation, the law prohibits payments by radioactive and other materials and products under the jurisdiction of the Russian Federation for the use of the subsurface.

The RFSSR law «On the Environment Protection» [4.31] determines ecological requirements when using radioactive materials. According to Article 50 of the law, the import of RW and/or of radioactive materials from foreign countries for storage/disposal, their marine and spaceward disposal and storage are forbidden.

In keeping with Article 51 of the Water Code [4.41], the disposal of potentially hazardous wastes is to be performed by permission of special state institutions of the Russian Federation authorized in the field of environmental protection in accordance with RF sanitary and epidemiological surveillance bodies.

The issues of NS utilization as well as of the management of SF and RW resulting from these activities are partly regulated by standard-legal decrees of both the RF President and the RF Government. The Decree of RF Government №505 of June 22, 1992 «On Approval of the Order of Inventory of the Extraction Sites as well as of Transportation, Treatment, Use, Collection, Storage and Disposal of RS and IRS within the Territory of the Russian Federation» [4.42] can be cited as an example. There are also a number of subordinated acts dealing with the issues under consideration.

RW are to be registered and controlled at both the federal and departmental levels [4.42].

The order of creating the system of state registration and control over both RS and RW is determined in the Regulation of the RF Government № 1298 of October 11, 1997 [4.43]. Minatom of Russia is made responsible for system creation and proper operation.

In pursuance of the above regulation, Minatom of Russia developed and put in force «The Regulation on State Registration and Control over Radioactive Materials and Radioactive Wastes in the Russian Federation» (registered in Ministry of Justice of Russia on the 11th of November, 1999, № 1976) [4.44]. Formats of on-line information related to the registration and control of RS and RW were also approved (Order № 449 of Minatom of Russia of July 24, 2000) [4.45].

To create a unified system regulating issues of RW handling, «the Concept of Minatom of Russia on Radioactive Waste Management» was developed (Order № 475 of Minatom of Russia of August 3, 2000) [4.46]. The Concept determines basic principles of RW handling and specifies main tasks of the technical policy. Thus, in keeping with the Concept, the fundamental principles of RW management are: - ensuring acceptable radiation levels from the viewpoint of the environment and human health protection against RW impact and - minimizing the economic burden on future generations. In accordance with the Concept, the amount of RW is to be kept at a minimal (practically attainable) level, and RW characteristics are to correspond to standards and rules in force in Russia in the field of the use of atomic energy and RW handling.

In keeping with the Concept, principal tasks of the technical policy are:

- continuation of work aimed at transforming accumulated RW as well as newly created RW into “safe” (i.e., conditioned) state,
- RW storage, and
- ensuring opportunities for subsequent RW disposal in keeping with principles, standards and rules in force in international practice.

Technological development and improvement of RW conditioning techniques are to be considered as “optimum solutions” of the concerned tasks. Requirements for standards of RW creation, for characteristics of conditioned wastes and for conditions of their temporary storage and disposal are also to be developed.

When RW handling, the control of the State over safety is carried out by state authorities entrusted with issues of safety (when using atomic energy) and by state surveillance bodies.

All activities dealing with RW are performed on the base of licenses granted by state safety regulating institutions when using atomic energy and by other state structures in keeping with the legislation in force.

4.2.4. Special Legal Regulation of the Issues of NS Utilization and Handling of SF & RW Resulting from this Process

The problem under consideration emerged first in the middle 1980s. It resulted from the decommissioning of a few of the earliest NS of the USSR, which needed further handling. Until then, no attention was given to the problem. During 1985 through 1992, based on decrees of the USSR (later on the RF) Government, a number of concepts of NS utilization were developed and the construction of the corresponding infrastructure started. E. g., on the 4th of May, 1991 a regulation “On Organization, Preparation and Salvaging of the Decommissioned Nuclear Submarines with Power Reactor Facilities” was approved by the RF Government. On the basis of the RF Government Decree of July 24, 1992 “On Actions to Perform Pilot Utilization of the Decommissioned Nuclear Vessels” [4.47] and the RF Government Decree № 644-47 of August 31, 1992, the construction of vessel-dismantling plant to carry out NS utilization began at «Nerpa» shipyard (May, 1993).

By special Decree of the RF President № 767 of July 28, 1995 all operations executed within the framework of the above regulation were raised to the category of “President Programs”, which provided for NS utilizing operations at a rate of five to six NS a year. (see Report of State Duma Commission – Decree № 3217 of RF State Duma of November 11, 1998) [4.48].

The “Federal Target Program (FTP) of Industrial Utilization of Armaments and Materiel for the Period up to 2000” approved by the RF Government Decree of May 25, 1994 laid the foundation of the “self-repayment” principle in the process of industrial utilization of armaments and materiel. To realize the Program, the RF Government Decree № 864 of July 17, 1996 was approved, which ratified “The Regulation on the Attraction of Resources from the Off-Budget Sources to Finance the FTP of Industrial Utilization of Armaments and Materiel for the Period up to 2000”.

The decree № 864 determined potential sources of the off-budget financing of the operations related to utilization of armaments and materiel including nuclear submarines. In keeping with the decree, all operations of surface vessel and diesel NS utilization are carried out at shipyards using the “self-financing” principle.

According to Item 5 of the Decree, a portion of the off-budget financing of NS utilizing operations can be provided by a part of the revenues of enterprises resulting from utilization product selling. This part is to be transferred to the RF Ministry of Defense in keeping with the terms of the corresponding contracts. According to the Regulation, the revenue resulting from selling of the utilization products is used to compensate the enterprise expenditures (related to the work under consideration), tax discharge and getting profits within a norm determined by the corresponding contract. The remaining part of the revenue enters a special account of the RF Ministry of Defense and is spent for the development and implementation of advanced and ecologically clean technologies of NS utilization, for the creation and development of utilization facilities and the other related ends.

On the 28th of May 1998, the RF Government approved the Decree № 518 «On Measures Aimed at Accelerating Utilization of Nuclear Vessels Decommissioned from the Navy and Ecological Rehabilitation of Radiation-Dangerous Installations of the Navy» [4.49], which provided for increasing the pace of NS utilization and rehabilitation of radiation and nuclear dangerous installations. In keeping with the Decree, a decision was made to transfer functions of ensuring safe waterborne storage and utilization of NS decommissioned from the RF Navy (untypical for this structure) to a special newly-created shipyards and self-sustained industrial enterprises of the State Russian Center of Atomic Shipbuilding (SRCASh). Correspondingly, the responsibility for the concerned operations was rested upon these enterprises.

The RF Ministry of State Property by its Decree № 1493 of November 23, 1998 approved the Order of transferring to work executors the decommissioned nuclear vessels (NS, surface vessels with PRF, diesel NS and servicing vessels) and installations of SF, LRW and SRW temporary storage under the RF Ministry of Defense. This was done in order to regulate the relations between the RF Government and federal executive body (including State Customer, the coordinator of multipurpose NS utilization, and temporary storage of SF, LRW and SRW), on the one hand, and the work executor, on the other hand. This document determines the units to be transferred to multipurpose utilization, the order and procedure of transferring and the standard-legal foundation of such actions. It is worth noting that the civil (i.e., contractual) mechanism was used in this process rather than the administrative (authoritative) approach. The above civil mechanism regulating legal procedures of the utilization process was developed in keeping with Article 220 of the RF Civil Code. According to the approved order, the RF Ministry of Defense transfers NS, surface vessels and servicing vessels decommissioned from the RF Navy to SRCASh enterprises and the Navy shipyards to perform their multipurpose utilization. This is done for purposes of compensating a part of the corresponding costs. The transferring of NS (owned by the State) is carried out in keeping with a contract for realizing multipurpose utilization of the decommissioned NS concluded between the State Customer - the work coordinator (Minatom of Russia) - and the work executors. The document of acceptance and transfer is approved by the territorial bodies of the RF Ministry of State Property and, subsequently, is transmitted to the Ministry. In keeping with the Order, the responsibility for respecting conditions of storage, radiation and ecological safety, and the undamaged state of NS rests on work executors.

The issues of financing of operations related to utilization and reducing of armaments in the Navy are regulated by the Decree № 226-25 of the RF Government of July 9, 1998. Individual organizational and financial issues of SF and RW handling (being accumulated due to the RF Navy operation) are regulated by the Decree № 220-r of the RF Government of February 9, 2000. The Decree regulates the creation of new state unitary enterprises. The enterprises are built in order to carry out operations related to handling of SF, SRW and LRW accumulated by the Navy and created in the course of NS utilization as well as to perform work on the ecological rehabilitation of radiation-dangerous installations in both Murmansk and Kamchatka regions. These are the «Northern Federal Enterprise on Radioactive Waste Management» and the «Far East Federal Enterprise on Radioactive Waste Management». Both enterprises are being created within the Minatom structure and are financed in keeping with the State Defense Order.

The issues of ensuring ecological safety when dealing with NS utilization and management of SF and RW resulting from this activity are regulated in a number of standard instructions of the RF President and Government. The most important documents are listed below.

Issues of handling of RW created in the process of NS utilization are regulated by the Decree № 710 of the RF Government of July 23, 1993 (in another edition № 1173 of October 7, 1996). This document is known under the name of «On Measures on Complex Solution of RW Handling Problem and on the Cessation of RW Sea Dumping» [4.50]. At that time (1993) Item 4 of the Decree was most important from the standpoint of ensuring the environment protection and ecological safety. The item 4 provided for «accepting proposal on the cessation of SRW sea dumping and ratifying ‘Temporary rules on LRW sea dumping’». Recall that at present as a result of Russian-Japan arrangements on the collaboration in the field of promoting for disarmament, a special Decision was made by the RF Government of August 8, 2000, according to which «Russia will forbear from RW sea dumping».

On the 6th of July 1994, the Decree № 805 of the RF Government «On Immediate Actions in the Field of RW and SF Management for 1994» [4.51] was approved. In this document a plan of actions was outlined to perform handling of SF and RW created by vessels of the Navy and Murmansk Sea Navigation Enterprise as well as by enterprises of the State Committee of Defense Industry.

The Decree № 1310 of the RF Government of October 31, 1996 «On Immediate Measures Aimed at Ensuring the Ecological Safety in the Russian Federation Armed Forces" [4.52] ratified a list of actions for 1997 through 2000 to be financed from the State Defense Order. These measures were focused on solving such tasks as: - ecological monitoring; - inventory of installations of the nuclear weapons complex; - developing and equipping Navy vessels with present-day systems of RW collection, accumulation and treatment; - building of coastal decontamination stations for the sake of the RF Navy, etc.

Another important source of legal regulation, as applied to safe handling of SF and RW created when utilizing NS, are Federal Target Programs (FTP) and Target Programs (TP) of the RF President. E.g., among the "President-status" TP, that of «Improving Nuclear Weapons Safety» approved by the Decree of the RF Government № 1103-66 of September 17, 1996 [4.53], can be cited.

FTP "Industrial Utilization of Armaments and Materiel for the Period up to 2000" was already mentioned above in the presented review. At present, a new complex program of armament and materiel utilization is being developed; part of this document deals with NS utilization issues.

FTP «Management of RW and Spent Nuclear Materials, their Utilization and Disposal for 1996 through 2005» [4.54] provided for execution of a number of actions related to handling of SF and RW resulting from NS utilization, in particular:

- making of transportation casks (TC), creation of transport facilities and auxiliary installations to ensure safe transportation of SF;
- creating appropriate equipment to utilize NS reactor spent fuel non-reprocessable at the present time;

- reconstructing operating facilities and creating of new facilities to perform conditioning and storage of RW at SRE “Atomflot”, at other shipyards and the Navy installations;
- developing technologies and making appropriate equipment to utilize NS reactor compartments;
- creating experimental industrial installations to dispose RW being created in the course of NS utilization; and
- creating industrial-type infrastructure of SF and RW management in Northwest and Far East regions of Russia, etc.

According to the Decree № 149 of the RF Government of February 22, 2000, the above FTP was declared invalid after January 1, 2001, and a new FTP was initiated and approved. The new FTP is known under the name of «Nuclear and Radiation Safety of Russia for the Period 2000 through 2006”[4.55]. The FTP is aimed at solving the complex issues of ensuring both nuclear and radiation safety in Russia including safety at shipbuilding enterprises when constructing, repairing and utilizing NS. The FTP also deals with the issues of RW and spent nuclear material management in order to minimize their hazardous impact on the environment and human beings.

Among others, the new FTP includes the following subprograms:

- handling of RW and spent nuclear materials, their utilization and disposal;
- nuclear and radiation safety at shipbuilding enterprises; and
- strategy of ensuring nuclear and radiation safety in Russia, etc.

Altogether there are 20 subprograms.

The realization of actions outlined in the FTP (if, in keeping with the FTP declarations, appropriate financing is provided) will make it possible to create reliable and safe technologies for utilizing nuclear units and installations and handling of SF and RW created in the course of the above operations. In particular, this will allow for ensuring safety when utilizing NS reactor compartments, developing and applying planning and design documentation and efficient transport and technologic schemes of handling of SF, RW and reactor compartments at shipbuilding enterprises, etc.

However, despite the fact that the issues of NS utilization, SF and RW management, ensuring the environment protection and the ecological safety in the course of the above activities are of great importance for the whole country, the FTP realization is restrained for lack of appropriate financing.

In the context of a rather difficult situation with the utilization of the decommissioned NS of the Navy, the RF State Duma passed more than once special resolutions (e.g.. № 1462 of June 4, 1997; № 2846 of July 16, 1998 and № 3217 of November 11. 1998). In these documents much anxiety was stated because of unsatisfactory financing of the considered work, especially in the Arctic Navy basing areas in Murmansk and Archangelsk regions. As was stressed in the Duma resolutions, financial resources to realize such an enormous work are extremely poor and even decrease further from year to year. Practically, the Decree № 864 of the RF Government of July 17, 1996 "On Approval of the Regulation on the Attraction of Resources from Off-Budget Sources to Finance the FTP 'Industrial Utilization of Armaments and Materiel for the Period up to 2000'" [4.56] has failed. The State Duma directed the attention of the RF Government to poor execution of Federal Target Programs as well as of President Programs in the field under consideration (in particular, of the PP № 767 of July 28, 1995).

The RF Government was entrusted with a task of developing a plan of attracting different-ownership organizations to the tasks of the program under consideration, enlarging international cooperation, concluding new intergovernmental agreements with foreign countries in the area of NS utilization and RW handling and keeping strictly to their terms.

Among activities outlined by the State Duma, the following actions are worthy of consideration:

- development of non-governmental international science-technical program on attracting additional financial and material resources to perform NS and RW utilization; and
- creation of a program of cooperation in the area of researches, assessment and selection of promising technologies of NS utilization and RW handling, building and equipping installations of their supporting infrastructure.

The tasks set by the Supreme Legislative Body in Russia in the field under consideration can be generalized as follows:

- full financing of NS utilization operations within the framework of the State Defense Order (up to now the share of the Navy orders in the State Defense Order decreased more and more; however even this "share" was not provided with finances in full measure);
- including the work under consideration into the Federal Law "On the Federal Budget" for the next fiscal year;

- financing the creation of regional centers (on the base of shipyards) to treat SRW within the framework of the Unified State Concept of RW Management;
- immunity from taxation (preferential terms with respect to VAT) for all operations related to NS utilization and, correspondingly, further development of Russian tax legislation, law of customs and credit policy in the area under consideration;
- toughening of the present-day system of licensing and certification of work as applied to shipbuilding, ship repair and atomic energy;
- implementing up-to-date utilization technologies, creating and developing specialized capacities to perform the tasks of NS utilization, improving nuclear and radiation safety;
- solving the problem of NS reactor compartment storage, SF temporary storage, SRW and LRW transportation (building and putting into operation of repositories and temporary storage sites of SF and SRW containers as well as of one-compartment units of reactor compartments; making unified units of equipment and fittings to unload and store SF, etc.).

It is planned that the above-listed tasks will be included into the Federal Law «On Industrial Utilization and Selling of Armaments, Materiel, Munitions and Installations», which is now under consideration and approval in the RF State Duma.

4.3. Branch (Departmental) Standard & Legislative Documents Regulating Issues of the Environment Protection and Ecological Safety during the Process of NS Utilization and Handling of SF and RW Resulting from These Activities

By the Order № 154 (N RD-06-01-93) of Gosatomnadzor of Russia of December 12, 1993, the Regulation «On the Order of Granting Temporary Licenses of Gosatomnadzor of Russia for Categories of Activities of Enterprises when Building Nuclear Vessels» [4.57] was approved. In keeping with this regulation, a special temporary license is necessary to perform storage, transportation and utilization of radioactive wastes.

By the Order № 48 (see edition of September 11, 1995) of Gosatomnadzor of Russia of April 14, 1994 the Regulation «On the Order of Granting Temporary Licenses of Gosatomnadzor of Russia for Categories of Activities of Enterprises when Repairing Nuclear Vessels» [4.58] was approved. Here it is stated that:

> “the availability of developed (in most detail) procedures of registration, storage and use of the equipment, devices and apparatus employing nuclear materials and radioactive substances, as well as of a well-organized system of performing operations with the use of the equipment, devices and apparatus employing nuclear materials and radioactive substances and products made on their basis is a necessary condition to obtain temporary licenses”.

Similar requirement is found in the “Regulations on the Order of Granting Particular Licenses of Gosatomnadzor for Activities of Enterprises when Repairing Nuclear Vessels” № 132 of December 12, 1994.

The issues of importation and exportation of nuclear materials, equipment and related technologies being “critical” from the viewpoint of nonproliferation of nuclear weapons are regulated by the following documents:

- The order № 103 of the RF Ministry of Foreign Economic Relations and Commerce of March 2, 1998 «On Improving Mechanisms of the Control over Export of Products & Technologies of Double Purposes and Critical Nuclear Production Related to Weapons of Mass Destruction and Missile Facilities for Their Haulage» [4.58];
- “The List of Nuclear Materials, Equipment, Special-Purpose Non-Nuclear Materials and the Related Technologies” approved by the Decree № 202 of the RF President of February 14, 1996, and the “Additions to the List” approved by the Decree № 468 of the RF President of May 12,1997; and
- “Regulations on the Order of Export & Import of Nuclear Materials, Equipment, Special-Purpose Non-Nuclear Materials and Related Technologies” approved by the Decree № 574 of the RF Government of May 8, 1996 [4.59]. (Note that the requirements of the Regulations include also issues of export/import of SF, which contains critical nuclear materials).

Licenses for the above group of products are granted to juridical persons only on the condition that they possess special permission of Gosatomnadzor of Russia to perform the concerned activity within the nuclear energy field.

Gosatomnadzor of Russia by its order №128 of November 14, 1994 approved the following regulations: «On the Order of Granting Temporary Licenses of Gosatomnadzor of Russia for Activities Related to Export/Import of Nuclear Materials, Technologies, Equipment, Installations, Special-Purpose Non-Nuclear Materials, Radioactive Wastes and Spent Nuclear Materials» [4.60].

On the 26th of June 1997, the RF Customs Committee issued the order № 01-14/796 «On the Order of Customs Procedures in Respect to Products Transported as Technical Assistance or to Products Temporarily Imported/Exported within the Framework of International Agreements in the Field of Disarmament[4]» [4.61]. This document determines the order of customs procedures related to products imported into Russia as free-of-charge technical assistance or products imported/exported temporarily within the framework of international agreements of Russia in the field of disarmament and restrictions of underground nuclear weapons testing. In particular, this concerned the Agreement between the Government of the Russian Federation and the Government of Norway on the Cooperation in the Field of Environment Protection Related to Utilization of the Decommissioned Russian Nuclear Submarines in the North Region and Ensuring Nuclear and Radiation Safety of May 26, 1998.

The requirements on obligatory certification of transportation casks to transport and store RW created in the course of NS utilization are listed in the joint order of RF Minatom, RF Gosatomnadzor and RF Gosstandard of April 24, 2000. The document is known under the name of: "On putting in force of the «Nomenclature of Equipment, Products and Technologies for Nuclear Installations, Radiation Sources and Sites of Storage to be Subject to Obligatory Certification within the Framework of the System of Certifying the Equipment, Products and Technologies for Nuclear Installations, Radiation Sources and Sites of Storage»" [4.62].

The above requirements are included into projects of NS utilization and handling of SF and RW realized on the basis of the corresponding directions and programs of the RF Government. Among such documents, the following ones should be mentioned:

- the above cited Regulation of the RF Government № 518;
- Federal Target Programs considered in the review (including FTP «Nuclide Materials, Products and Prospective Technologies on Their Basis»); and

[4] see Directions of the RF Customs Committee: № 01-14/1528 in edition of November 6, 1997; № 01-14/627 in edition of June 11, 1998; № 01-14/529 in edition of April 22, 1999; № 01-14/644 in edition of June 3, 1999 and № 935 in edition of December 30,1999.

- international programs and multilateral international projects (e.g., Transportation Cask - Metal-Concrete Container – RBMK; Multipurpose Utilization of «Lepse» Floating Enterprise: «Murmansk Initiative - RF», etc.).

4.4. Management Directives on Ensuring the Radioecological Safety at Enterprises Dealing with NS Utilization

4.4.1. General Positions

The handling of every type NS after the decommissioning begins only following the development of an appropriate utilization program and project. The utilization program determines stages and the sequence of work with consideration for both the NS technical state and the readiness of the supporting infrastructure. Within the utilization project, technological issues of operations to be performed are determined, and all types of needed documents (project, design as well as technological, organizational and administrative documentation) are developed. The scheme of developing a NS utilization project is presented in Figure 4.2.

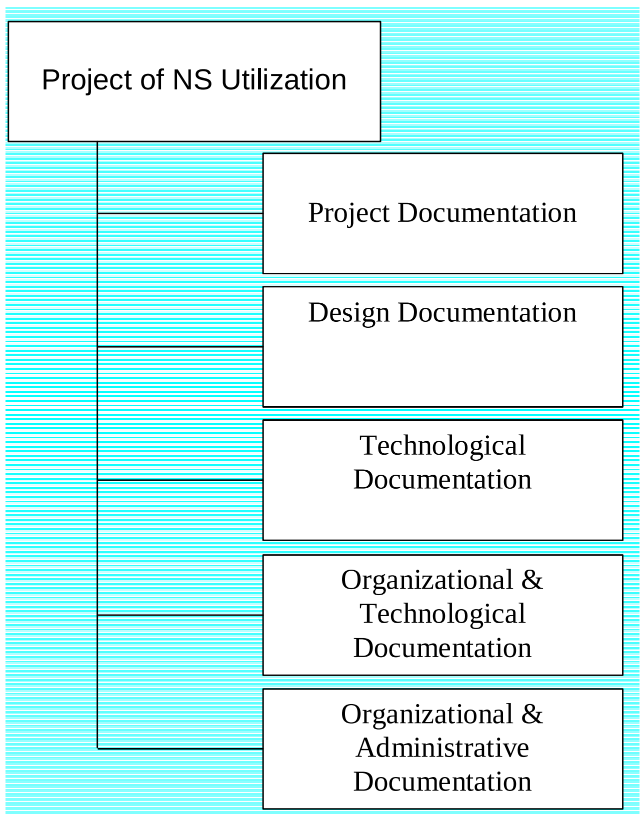

Figure 4.2. Scheme of Utilization Project Development

Every package of developed project, design, technological et al., documentation is to include specific standard-legal provisions to ensure technical, nuclear, radiation and ecological safety at different stages of NS utilization; by this are realized the requirements of standard and legal documentation of upper levels.

4.4.2. Design Documentation

Figure 4.3 demonstrates the principal stages of NS utilization for which appropriate design documentation is developed.

This documentation category comprises the following types of documents:

«Instruction on Nuclear Safety when NS Decommissioning»;
«Schemes of Accessway to Reactor Compartment»;
«Calculations of Buoyancy and Stiffness»; and
«Technical Project of Reactor Compartment Unit Haulage».

Central Design Office (CDO) - the designer of every NS project - determines conventional packages of design documentation to be developed for every NS design individually and submits these documents for the General Customer's approval.

4.4.3. Project Documentation

«Estimate of the Impact on the Environment» (developed for Every Project);

«Radiation & Hygienic Requirements for Handling of NS to be Utilized»;

«List of Radiation-Dangerous Operations and Organizational-Technical Measures to Undertake when Utilizing NS»;

«List of Potential Nuclear-Hazardous Operations and Technical Requirements to Be Respected when Utilizing NS»;

«Calculation of Boundaries of SRCASh Enterprise Buffer Area when Utilizing NS»;

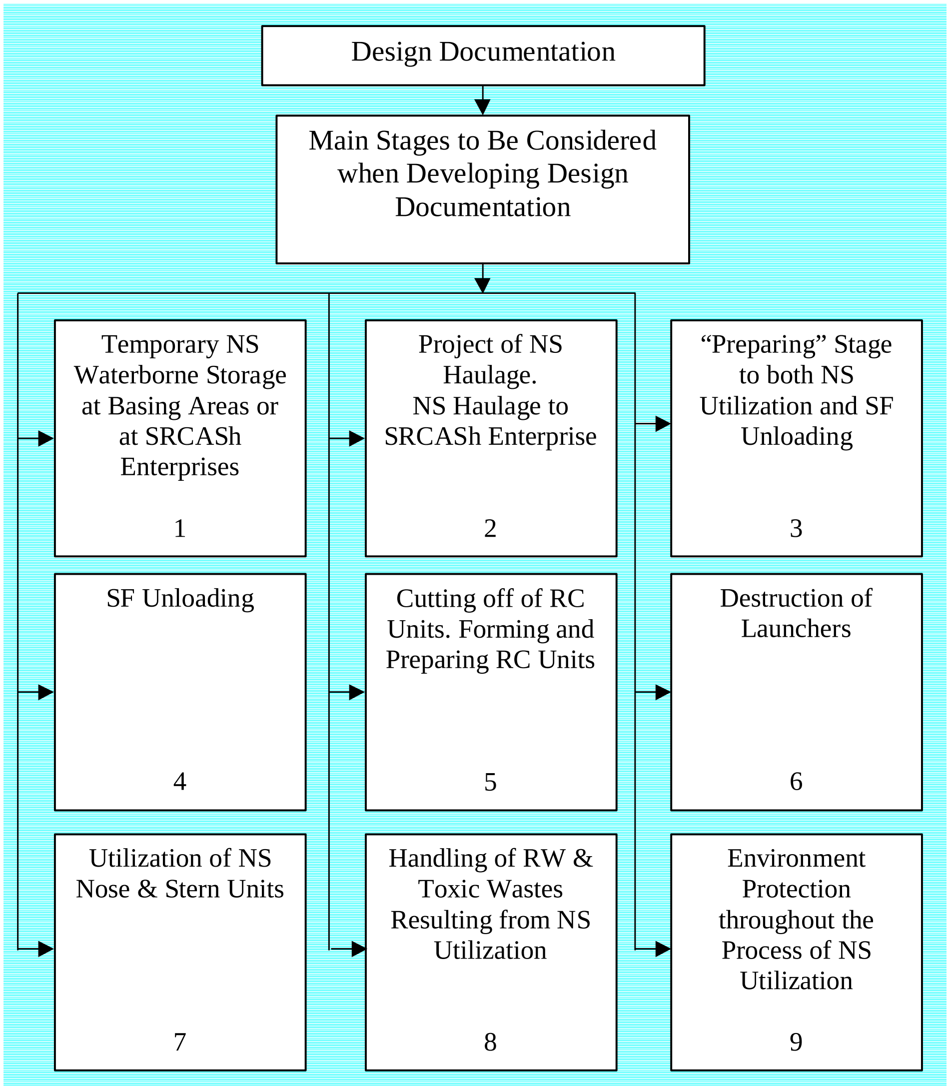

Figure 4.3 Principal Stages of Utilizing Nuclear Submarines for which the Design Documentation Have Been Developed

«Basic Principles of the Radiation & Ecological Safety when Carrying out NS Utilization and RW Handling»;

«Project and Instruction on Safe NS Haulage to SRCASh Enterprise and RW Transportation to Storage Site and (or) Temporary Storage Site»;

«Technical Project of Maintenance Systems to Perform NS Utilization»; and

«Radiation-Hygienic Requirements to Justify SRW Loading into Reactor Compartment».

4.4.4. Technological Documentation

«Basic Statements. Ensuring the Radiation Safety when Utilizing NS»;

«Basic Statements. Toxic Industrial Wastes Generated in the Process of NS Utilization»;

«Technological Scheme of Management of RW Created when Utilizing NS»;

«Basic Statements. SF Unloading when Performing NS Utilization Operations».

4.4.5. Organizational-Technical Documentation

«Ecological & Radiation Characteristics ("Passport") of SRCASh Enterprise»;

«Standard Plan of Actions on the Personnel & Population Protection in Case of Radiation Accident at SRCASh Enterprise»;

«Analysis of Implications of Potential Radiation Accidents in the Course of NS Utilization. Radiation Risk Assessment»;

«Physical Protection. Materials on Ensuring Physical Protection of PRF of NS when Performing NS Utilization at SRCASh Enterprise»; and

«Technological Schedule in the Course of SF Handling Operations at SF Reloading Sites».

The radiation monitoring in the environment and the control over exposure of both personnel and population at enterprises concerned with NS utilization is performed in keeping with "Methodical Instructions" approved by both the branch leaders and the RF Chief Sanitary Inspector.

The responsibility for respecting the requirements of the above Instructions is determined by "Basic Sanitary Rules of Ensuring the Radiation Safety (BSRERS) - 99" [4.63] and rests with the direction of the enterprises-work executors. The control over their observance rests upon entities of Gosatomnadzor of Russia.

By "the control over the environmental contamination" is meant:

control of the environmental media contamination by radioactive substances as a result of operations carried out at enterprises;

control of the environment media contamination by radioactive substances from external (with respect to the enterprise) sources including global fallout;

control of external exposure levels and contamination of surfaces resulting from installations located within the territory (water area) of the enterprise as well as indoors outside the strict regime zone; and

control over radionuclide concentrations in releases and effluents of the enterprise installations.

Since the radiation impact of enterprises dealing with NS utilization can go beyond their sites, two further types of special-status territories are arranged, i.e., the Buffer Area (BA) and the Radiation Control Area (RCA). Their boundaries are determined on the basis of calculations of the population effective exposure dose (see Tables 4.1 through 4.3).

Table 4.1. Maximum Allowable Levels (MAL) of the Integral Volumetric Activity and of the Activity of Most Important Radionuclides in the Air of BA & RCA, Bq/m^3

β-radiating elements			**α-radiating elements**		
Nuclide	BA	RCA	Nuclide	BA	RCA
^{60}Co	$4.2 \cdot 10^{-2}$	$4.5 \cdot 10^{-3}$	^{238}Pu	$1.2 \cdot 10^{-4}$	$1.3 \cdot 10^{-5}$
^{90}Sr	$8.4 \cdot 10^{-2}$	$8.9 \cdot 10^{-3}$	^{239,240}Pu	$5.0 \cdot 10^{-5}$	$5.3 \cdot 10^{-6}$
^{106}Ru	$4.2 \cdot 10^{-2}$	$4.5 \cdot 10^{-3}$	^{241}Am	$1.1 \cdot 10^{-4}$	$1.1 \cdot 10^{-5}$
^{134}Cs	$8.4 \cdot 10^{-2}$	$8.9 \cdot 10^{-3}$	^{242}Cm	$1.3 \cdot 10^{-4}$	$1.3 \cdot 10^{-5}$
^{137}Cs	$5.0 \cdot 10^{-1}$	$5.3 \cdot 10^{-2}$	^{244}Cm	$2.1 \cdot 10^{-5}$	$8.2 \cdot 10^{-6}$
^{144}Ce	$8.4 \cdot 10^{-2}$	$8.9 \cdot 10^{-3}$			
Integral β-activity	$3.3 \cdot 10^{-1}$	$3.5 \cdot 10^{-2}$	Integral α-activity	$7.2 \cdot 10^{-5}$	$1.1 \cdot 10^{-5}$

Table 4.2. MAL of the Integral Activity of Depositions, kBq/m^2

Area	**BA**	**RCA**
Sampling Period	Month	Quarter
β-activity	2.7	0.9
α-activity	$0.6 \cdot 10^{-3}$	$0.3 \cdot 10^{-3}$

Table 4.3. MAL of Radionuclides in Marine Water & Bottom Sediments

Nuclide	**Marine water, Bq/l**	**Bottom sediments, kBq/kg**
^{60}Co	1.0	11.0
^{90}Sr	1.8	1.8
^{137}Cs	1.7	4.5

4.4.6. Current Control

The current control is principally aimed at revealing cases of MAL excess. Such cases are to be examined, and their causes are to be eliminated.

The control is carried out at permanent control points using maps agreed with RF State Sanitary Inspection bodies. Principally, the control points are located close to areas of both radiation-dangerous operations and RW handling installations.

Within the BA of the concerned enterprises (note that both "dry land" and "water area" are surveyed) the following parameters are controlled:

- external radiation levels;
- surface contamination;
- air contamination;
- bottom sediment contamination; and
- marine (river) water and hydrobionts (if necessary).

Control points are chosen in such a way as to ensure:

- maximum representativeness of the samples taken (especially in areas of performing radiation-dangerous operations, of locating RW repositories and/or RW temporary storage sites); and
- ability to compare contamination levels throughout the period of the enterprise operation; for this purpose, basic points of measurements should be located at the same areas, where possible.

In settlements located within RCA are controlled:

- atmospheric air;
- external radiation levels and surface contamination in the most-visited areas, at dumps and sites of domestic waste collection and storage; and
- water area (if necessary).

In areas with background radionuclide concentrations, all the above-listed environment parameters are surveyed. Here, control points are placed in such a way as to exclude the enterprise radiation impact on the environmental components.

4.4.7. Additional Control at the Enterprises dealing with NS Utilization

At enterprises involved in NS utilization, the “Current Control” is supplemented by so-called “Additional Control” organized with consideration for the specificity of utilization operations and areas where they are carried out. When developing the “Additional Control” provisions, attention is principally focused on opportune revealing of radionuclide releases in the environment.

Thus, the additional control includes:

- monitoring of secondary materials created when utilizing NS; and
- monitoring of water areas wherein cut-off reactor compartments or reactor compartment units are temporarily stored afloat.

The control over secondary materials is mainly aimed at:

- obtaining reliable information on the availability/unavailability of secondary material contamination;
- eliminating the use in the national economy of secondary materials contaminated above MAL; and
- ensuring conditions for separate use of different-degree contaminated secondary materials in the national economy.

Every lot of secondary materials is controlled via measuring γ dose rate on the lot surface. In a case of scrap metal lots (considered as the “second” or the “third” radiation category) an additional control to reveal the surface contamination by α-emitting nuclides is performed, and the radionuclide composition is measured. The results of measurements are compared with MAL.

The methods of radiation control over the secondary materials should allow for revealing local γ-radiation sources within the secondary material lot. By this is meant the availability of samples with surface γ dose rate over 0.2 μSv/h or with an excess of γ dose rate by a factor of two at least, as compared to the average value of the whole lot. Such control makes it possible to form homogeneous lots of secondary materials from the viewpoint of their radioactive contamination.

The radiation monitoring over secondary materials created during NS utilization process is performed at three stages:

- primary radiation examination is carried out in the course of both the equipment dismantling and the vessel hull cutting off using low-inertia highly sensitive portable dosimeters (employed as "survey" devices);
- reexamination is performed at storage sites when loading scrap metals into standard boxes after their sorting out. When performing such measurements, portable dosimeters or sensitive automated radiation control devices (with several detection units) can be used. This allows for on-line estimating the distribution of gamma dose rate on the lot surface, determining its average value, revealing local contamination sources or confirming ultimately their unavailability and, finally, placing the lot under consideration into one or another radiation category; and
- ultimate γ dose rate measurements of scrap metal lots are performed following loading into standard containers or after obtaining standard-size packages at the packing press. Measurements are performed prior to sending packages to a repository of merchantable scrap storage or after their loading into transport facilities. When measuring, portable dosimeters are used or a dosimeter device with some detection units.

The monitoring of both empty packages and transport facilities aimed at storing and transporting metal scram is performed routinely.

In water areas of temporary waterborne storage of cut off reactor compartments or reactor compartment units, radiation monitoring of marine water, bottom sediments and algae is performed.

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